CHIP CHARACTERIZATION: MAN-HOUR REDUCTION AND INCREASED FUNCTIONALITY TESTING WITH AUTOMATION IMPROVEMENTS

THESIS

Presented to the Graduate Council of
Texas State University-San Marcos
in Partial Fulfillment
of the Requirements

for the Degree

Master of SCIENCE

by

Robert C. Murphy, PhD, M.S., B.S.

San Marcos, Texas
May 2007

CHIP CHARACTERIZATION: MAN-HOUR REDUCTION AND INCREASED FUNCTIONALITY TESTING WITH AUTOMATION IMPROVEMENTS

Committee Members Approved:

Deborah East

Jawad Drissi

Granville Ott

Approved:

J. Michael Willoughby
Dean of the Graduate College

ACKNOWLEDGEMENTS

I am very thankful to Dr. East, Dr. Otto, and Dr. Drissi for their guidance and support. I would also like to thank the company C.L. for presenting and allowing me to work on this problem. It has been a very intense and rewarding experience. I would also like to thanks the engineers for their invaluable assistants.

This manuscript was submitted on March 6, 2007.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS iii

ABSTRACT xii

CHAPTER 1 1

BACKGROUND 1

INTRODUCTION 1

1.1. Project Motivation 1
- 1.2. Project Description 4
- 1.3. Software Platform Used to Implement System 7
- 1.4. Summary of Interview / Knowledge Acquisition 7
- 1.5. Additional Existing Documents, Synonyms, etc. 10
- 1.6 Organization of Thesis 10
- 1.7. Background 11
  - 1.7.1 Resolution 13
  - 1.7.2 Range 15
  - 1.7.3 Amplification 16
  - 1.7.4 Code Width 17
  - 1.7.5 Conversion Errors 20

CHAPTER 2 29

PERFORMANCE METRICS FOR ADC 29

INTRODUCTION 29
- 2.1 Static Performance 30

2.1.1 Histogram Analysis 30
2.1.2 Gaussian 31
2.1.3 DNL Affect on Histogram 35
2.1.4 Averaging 36
2.1.5 Flicker Free Bits 37
2.4 Dynamic Performance 39
2.4.1 Windowing 40
2.4.2 Signal Analysis Statistics 46
CHAPTER 3 48
ANALYSIS APPLICATION 48
CHAPTER 4 57
UML 57
INTRODUCTION 57
4.1 General Description for ADC Family 58
4.1.1 UML Class Model 64
4.1.2 UML State Model 65
4.2 Microcontroller 84
4.3 Bench Test Environment 91
4.3.1 Class Model 92
4.3.2 State Model 93
4.3.3 Interaction Model 95
4.4 Automation Test Environment 106
4.4.1 Class Model 107
4.4.2 State Model 109

4.4.3 Interaction Model 115

CHAPTER 5 116

IMPLEMENTATION 116

INTRODUCTION 116

5.1 PROTOCOLS 117

5.1.1 SPI 117

5.1.2 GPIB 118

5.1.3 RS485 119

5.1.4 Peripherals Interfacing 119

5.2 User Interface 134

CHAPTER 6 163

CONCLUSION 163

BIBLIOGRAPHY 164

LIST OF TABLES

TABLE 1 CALCULATED LSB VALUES FOR DIFFERENT RESOLUTIONS...... 19
TABLE 2 IDEAL RESOLUTION.. 19
TABLE 3 IDEAL SIGNAL-TO-NOISE 20
TABLE 4 WINDOWS METRICS 45

LIST OF FIGURES

FIGURE 1 OVERALL PROJECT LAYOUT 4
FIGURE 2 INPUT SIGNAL SINE WAVE 100 HZ... 14
FIGURE 3 ADC 3 BIT CONVERSION OF SINE WAVE 14
FIGURE 4 ADC 16 BITS CONVERSION OF 100 HZ SINE WAVE 15
FIGURE 5 RANGE (0-10)V AND (-10 TO +10)V... 16
FIGURE 6 ADC 3-BITS CODE WIDTH AND TRANSITIONS............................ 18
FIGURE 7 DIFFERENTIAL NONLINEARITY 22
FIGURE 8 INTEGRAL NONLINEARITY.. 23
FIGURE 9 OFFSET ERROR 24
FIGURE 10 GAIN ERRORS 25
FIGURE 11 ALIAS TIME DOMAIN SIGNAL 26
FIGURE 12 ALIASING IN THE FREQUENCY DOMAIN 28
FIGURE 13 NON-IDEAL ADC HISTOGRAM 31
FIGURE 14 GAUSSIAN NOISE AND PDF 32
FIGURE 15 HIGH DNL AFFECT ON HISTOGRAM 35
FIGURE 16 PERIODIC AND NON-PERIODIC ANALOG SIGNALS 40
FIGURE 17 FFT PERIODIC AND NON-PERIODIC SIGNAL 41
FIGURE 18 SINE WAVE WINDOWED WITH HAMMING 42
FIGURE 19 MAINLOBE AND SIDELOBE OF WINDOWS 43
FIGURE 20 FREQUENCIES BLEARING FROM WINDOWING........................ 44
FIGURE 21 WINDOWS SINE WAVE PLOT.. 46
FIGURE 22 BASIC DYNAMIC PERFORMANCES.. 49
FIGURE 23 POWER SPECTRUM OF SIGNAL 50
FIGURE 24 SNR FLOW CHART.. 51
FIGURE 25 SDR DIAGRAM.. 52
FIGURE 26 SDR FLOWCHART.. 53
FIGURE 27 SIGNAL TO PEAK NOISE MAPPING.. 54
FIGURE 28 SPN PSEUDO-CODE 55
FIGURE 29 PSEUDO-CODE FOR SINAD 56
FIGURE 30 CS5530 ADC INTERNAL... 59
FIGURE 31 FRONT END CONFIGURATION 59
FIGURE 32 CS5530 REGISTERS 60
FIGURE 33 CS5531/32/33/34 ADC INTERNAL 61
FIGURE 34 CS5531-34 FRONT END 62

FIGURE 35 CS5531/32/33/34 REGISTER DIAGRAM 63
FIGURE 36 CLASS DIAGRAM OF DUT 65
FIGURE 37 SYSTEM INITIALIZATION 67
FIGURE 38 ADC RESET STATE MODEL 68
FIGURE 39 READ, WRITE, AND DATA CONVERSION TIMING DIAGRAMS .. 69
FIGURE 40 WRITE CYCLE.. 70
FIGURE 41 READ CYCLE STATE MODEL 71
FIGURE 42 SINGLE DATA CONVERSION 72
FIGURE 43 LOAD COMMAND SUB-STATE OF DATA CONVERSION 73
FIGURE 44 CONFIGURATION REGISTER PIN OUT 74
FIGURE 45 READ REGISTER STATE MODEL.. 75
FIGURE 46 WRITE REGISTER STATE MODEL 76
FIGURE 47 SELF CALIBRATION STATE MODEL CS5531-5534 78
FIGURE 48 SYSTEM CALIBRATION STATE MODEL FOR CS553X 79
FIGURE 49 CONVERSION REGISTER DATA OUTPUT DESCRIPTIONS....... 80
FIGURE 50 CS5530 CONVERSION DATA OUTPUT DESCRIPTIONS 81
FIGURE 51 SINGLE DATA CONVERSION STATE MODEL 82
FIGURE 52 CONTINUOUS CONVERSION STATE MODEL............................ 83
FIGURE 53 BOARD LAYOUT 84
FIGURE 54 C8051F320 MICROCONTROLLER INTERNAL LAYOUT 87
FIGURE 55 C8051F320 BLOCK DIAGRAM.. 88
FIGURE 56 USBXPRESS DATA FLOW 89
FIGURE 57 EXPRESS API FOR PC AND DUT (DEVICE UNDER TEST) 90
FIGURE 58 MICROCONTROLLER STATE MODEL 91
FIGURE 59 BENCH TEST CLASS MODEL.. 92
FIGURE 60 BENCH TEST STATE MODEL 94
FIGURE 61 USE CASE DIAGRAM FOR POWER SUPPLY 102
FIGURE 62 SILICON THERMAL USE CASE DIAGRAM................................. 103
FIGURE 63 DUT USE CASE DIAGRAM... 104
FIGURE 64 EVALUATION SOFTWARE SEQUENCE “EVAL553X_U.EXE” ... 105
FIGURE 65 AUTOMATION LAYOUT... 107
FIGURE 66 AUTOMATION CLASS MODEL... 108
FIGURE 67 AUTOMATION POWER INITIALIZATION STATE MODEL 110
FIGURE 68 SETTING POWER SUPPLY VOLTAGES AND CURRENT VALUES 112
FIGURE 69 SILICON THERMAL TEMPERATURE VALUES........................... 114

FIGURE 70 TEST ENGINEERS AND TESTERS RELATIONSHIP TO AUTOMATIC TEST ENVIRONMENT 115
FIGURE 71 DATA SOURCE SELECTION 137
FIGURE 72 SUCCESSFUL COMMUNICATION 138
FIGURE 73 VERSION IDENTIFICATIONS 139
FIGURE 74 MENU DRIVEN 140
FIGURE 75 SETUP PANEL 141
FIGURE 76 SINGLE CONVERSION MODE USING SOFTWARE TIMER 143
FIGURE 77 CALIBRATION 144
FIGURE 78 CHANNEL SETUP PANEL 145
FIGURE 79 DATA COLLECTION WINDOW (ANALYSIS) 146
FIGURE 80 CONFIGURATION PANEL (# SAMPLES, AVERAGE, FFT WINDOW, HISTOGRAM WIDTHS) 147
FIGURE 81 CONFIGURATION SAMPLE NUMBER DROP DOWN LIST 148
FIGURE 82 TIME DOMAIN 1024 SAMPLES 149
FIGURE 83 FFT OF CONVERTED DATA 150
FIGURE 84 ZOOM SEGMENT OF THE PLOT 151
FIGURE 85 ERROR MESSAGE WHEN CURSORS ARE OUT OF ORDER ... 152
FIGURE 86 HISTOGRAM OF ZERO VOLT INPUT 153
FIGURE 87 AVERAGE PLOTTED 2 154
FIGURE 88 AVERAGE PLOTTED 10 155
FIGURE 89 NO CALIBRATION 156
FIGURE 90 WITH OFFSET AND GAIN CALIBRATIONS 157
FIGURE 91 AUTOMATION PANEL 158
FIGURE 92 CS5530 SETUP PANEL 161
FIGURE 93 CS5530 DATA COLLECT PANEL 162

LIST OF EQUATIONS

EQUATION 1 CODE WIDTH 17
EQUATION 2 IDEAL CODE WIDTH CALCULATION 19
EQUATION 3 SIGNAL TO NOISE RATIO 20
EQUATION 4 ANALOG TO DISCRETE SIGNAL REPRESENTATION 26
EQUATION 5 ALIAS FREQUENCY GENERATED 27
EQUATION 6 GAUSSIAN PROBABILITY DENSITY 32
EQUATION 7 MEAN 32
EQUATION 8 STANDARD DEVIATION OF DIGITIZED SIGNAL 32
EQUATION 9 SNR CALCULATION WITH NOISES 37
EQUATION 10 WINDOWING FREQUENCY RESOLUTION 44
EQUATION 11 SIGNAL-TO-NOISE RATIO 48
EQUATION 12 SIGNAL-TO-NOISE PLUS DISTORTION 48
EQUATION 13 SIGNAL-TO-DISTORTION RATIO 48
EQUATION 14 SIGNAL-TO-PEAK NOISE 48

ABSTRACT

CHIP CHARACTERIZATION:
MAN-HOUR REDUCTION AND INCREASED FUNCTIONALITY TESTING
WITH AUTOMATION IMPROVEMENTS

by

Robert C. Murphy

Texas State University-San Marcos

May 2007

SUPERVISING PROFESSOR: DEBORAH EAST

Chip design expansion increases linearly with new products, thus device characterization tests have increased exponentially and created a chip design bottleneck. If there is only one function (herein designated as “A”), “A” need only test function “A.” If there are two functions, “A” and “B”, then test sets will be “A,” “B,” “AB,” and “BA.” If there are three functions, ”A,” “B,” and “C,” then test sets “A,” “B,” “C,” “AB,” “AC”, “BA,” “BC,” “CA,” “CB,” “ABC,” and so forth.

The objective of this thesis is to automate manual test procedures so that design bottlenecks can be eliminated and device characterization can be improved. In achieving the stated objective, it will be necessary to develop a framework that attains and integrates commonality, maintainability, and reusability.

CHAPTER 1

BACKGROUND

INTRODUCTION

1.1. Project Motivation

C.L. Corporation (C.L.) is a major producer of industrial chips used in oil exploration, residential power consumption and weigh scale application. C.L. is also a leading producer analog to digital converters, (ADC). Chip design expansion increases linearly with new products, thus device characterization tests have increased exponentially and created a chip design bottleneck. If there is only one function (herein designated as “A”), “A” need only test function “A.” If there are two functions, “A” and “B”, then test sets will be “A,” “B,” “AB,” and “BA.” If there are three functions, ”A,” “B,” and “C,” then test sets “A,” “B,” “C,” “AB,” “AC”, “BA,” “BC,” “CA,” “CB,” “ABC,” and so forth.

C.L. characterization engineers find it challenging to keep up with the demands placed upon them. Chip validation procedures focus on everything from highly integrated analog and digital tests to system level power management and custom “system on” chip tests.

The objective of this project is to automate C.L.’s manual test procedure so that design bottlenecks can be eliminated and device characterization can be improved. In achieving the stated objective, it will be necessary to develop a framework that attains and integrates commonality, maintainability, and reusability.

Currently, C.L. device characterization is a highly manual process that involves extensive operator intervention and control. The engineer manually sets up the power supplies, device temperature, writes to the DUT (device under test), then records multi-meter measurements by hand. This process is tedious, time consuming, and lends itself to errors. In essence, a typical validation procedure requires the use of at least four different instruments which results in the necessity of four different protocols to control the instruments.

Each instrument has its own exclusive control language. Power meter, ADC microchip validation/characterization, and testing procedures utilize RS-232, RS-485, GPIB (IEEE-488), and USB 2.0 protocols. Power supplies and digital multi-meters use GPIB. Silicon Thermal DUT temperature set uses RS-232 and a network version of RS-232 called RS-485. The (customized) board which holds the DUT uses USB 2.0 to communicate with the microcontroller, and the microcontroller then communicates with the chips on the evaluation board. The microcontroller uses protocols I2C or SPI for chip communication.

In this project, I shall integrate source and measurement equipment with the customized board to test microchips. In personal interviews with C.L.'s engineers, four crucial criteria emerged as follow:

- Ease of use
- Modularity
- Interchangeability
- Flexibility

The key project goal is to improve C.L.'s test methodologies by automating testing techniques. The test project should use easy, flexible, modular, interchangeable components. Whenever feasible, the interface screen should match as closely as possible to the actual test measurement instruments.

The programming language used to set up the aforementioned methodologies shall be Labwindows.

1.2. Project Description

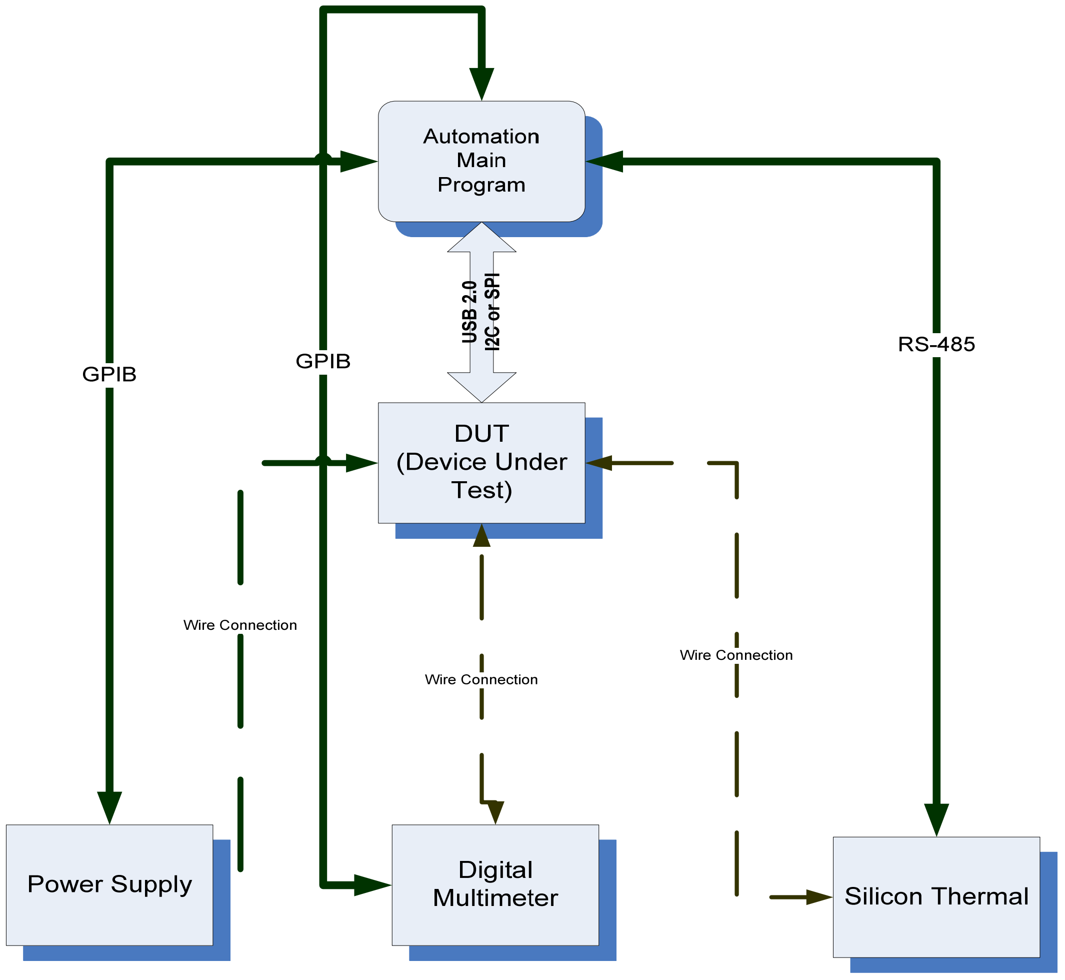


FIGURE 1 OVERALL PROJECT LAYOUT

Once again, the objective of this project is automating the chip validation procedure and developing a technique for testing specific functions of a chip. To achieve this task I grouped the project into three phases. Phase 1 is developing an application to communicate with the test chips, phase 2 is developing drivers to communicate with the test instrument, and phase 3 is integrating phase 1 and phase 2 together resulting in the automatic tester. Figure 1.1 shows the layout of this project.

This application overcomes the human error and speed up the validation procedure. It is design based on the concept of virtual instrument. Virtual instruments describe the combination of programmable instruments with general-purpose PCs. Virtual instruments contain a GUI for controlling its functions by the PC. A test engineer can easily set the peripherals for several values that are automatically changed by the host computer during a run. The output consists of test output parameters, peripherals values, and chip register values.

Product Features and Benefits:

- *Automatic so reduction in human error*
- *Reduction in man hours for validation*
- *Accuracy in test setup and reading*
- *Easy to use*
- *GUI for each peripheral*
- *User Friendly*
- *Product Constraint:*
- *Graphical User Interface*

- *Automatic setting of peripherals*
- *Automatic setting of Chip register values*
- *All register values and peripherals setting store in a file*
- *Stand alone operation*
- *Monitors: 800x600 minimum resolutions at 256 colors*
- *Computer with GPIB card, RS232 port, and USB port*
- *I/O: One or two button mouse and standard 101-key board*
- *Mhz: PIII 1.0 Ghz*
- *Power Supply with GPIB or RS232 port (HP3458)*
- *Keithley Digital Multimeter 197A GPIB port*
- *Silicon Thermal Temperature controller with RS232 port*
- *Power Setting up to 10 values*

Hardware Constraint:

- Monitors: 800x600 minimum resolutions at 256 colors
- Computer with GPIB card, RS232 port, and USB port
- I/O: One or two button mouse and standard 101-key board
- Mhz: PIII 1.0 Ghz
- Power Supply with GPIB or RS232 port (HP3461A)
- Keithley Digital Multimeter 197A GPIB port
- Silicon Thermal Temperature controller with RS485 port

Assumptions:

- Above instrument are available
- Tester and/or Test Engineer knows how to connect GPIB devices
- Tester and/or Test Engineer comfortable with windows and mouse
- Tester and/or Engineer knows excel spreadsheet and how to import
- USB 2.0 communication is bug free

1.3. Software Platform Used to Implement System

I used LabWindows/CVI to develop this application. LabWindows/CVI is a test and measurement ANSI C development environment. It includes a 32-bit compiler and linker with advanced editing and debugging tools.[1][2] It is open which means one can incorporate other compilers and produce DLLs for other environments. LabWindows/CVI includes a comprehensive suite of libraries targeted at instrumentation applications, from instrument control to data analysis and graphing. It also includes CodeBuilder and interactive function panels. [3]

1.4. Summary of Interview / Knowledge Acquisition

Robert: Hi M S how are you doing today?
M S: I am doing great.

Robert: How is the new born and has your daughter accepted him yet?
MS: New born is fine and no, the daughter has not accepted him.

Robert: Well, how is work going in the industrial group?

MS: Well, it would be a lot better if we had the test procedure automated. I have several new chips coming in that need to be validated.

Robert: What is it that you need to automate and how can I help?
M S: As you know we have a test board and have a chip that we place on the board. The board is connected to the host computer through the USB port. We would like an application to communicate with the chip and write to different registers on the chip.

Robert: What type of protocol are you using to communicate with the device under test?
M S: I think that it is SPI to write to the register and to read information from the registers.

Robert: So what are some of the test features that you want to do on the chip?
M S: Well, I would like Normal test of the chip and several signal analysis tests on the chip.

Robert: What type of signal analysis test on the chip that you would like?
M S: Signal FFT and Noise FFT.

Robert: What else would you like in your output?
M S: Well, I would like to see plots Fast Fourier Transforms and magnitude and phase of the signal.

Robert: What else would you like?
M S: I would like for it to be totally automated.

Robert: Please elaborate.
M S: On the test board there are plug-ins for power connection. I would like to adjust the different power supply setting automatically. Also, there are jumpers that come off the board. Do you know what jumpers are?

Robert: Yes, I understand.
M S: These jumper output voltage values on the board that tell what the output of the chip is. I would like to store those values in to a file somehow with the chip configuration.

Robert: That wouldn’t be a problem. What format would you like the output to be?

M S: I would like to be able to open the output file into an excel spreadsheet. The tester should able to do analysis on the output file values.

Robert: How many power supplies will be used to connect to the testing board to power up the chip?
M S: There will be only one power supply powering the board and the test chip. There also will be two digital multimeters to read the value of the header or jumpers. And there is a thermal controller that needs to be adjusted. It sets the temperature value of the device.

Robert: What is the interface protocol for these devices?
M S: The protocol is RS 232 and GPIB and the board is connected to the host computer through the USB bus.

Robert: If you are using the GPIB, there needs to be a PCI-GPIB card or usb-GPIB device connected to the computer to communicate to GPIB devices. Do you have a card?
M S: Well, we probably have one floating around, if not we will order what ever you need to interface to the instrument.

Robert: What programming language do you want to use?
M S: Well, I would like it to be written in Labwindows and/or Labview.

M S: Do you know Labview or Labwindows?
Robert: Well, I am a Labview expert but I don't know Labwindows at the moment. It should not take me long to figure it out though.
M S: Great.

Robert: Do you mind if I record our interview for my thesis?
M S: No problem at all feel free to use it and my name.

Robert: I won't use your name or the company name directly. I will just use an alias for the company and your name.
M S: That is okay.

Robert: Is there anything else you would like to add at this moment.
M S: No, I think that I have covered everything so far.

Robert: Well, thanks for the interview and I will start right away on designing the prototype of the interface and other stuff so that you and your engineer can overview it.

M S: Thanks.
Robert: No thank you. This should be a fun project and feel free to contact via email or through the phone if you have any last minute suggestions.

1.5. Additional Existing Documents, Synonyms, etc.

GPIB- General Purpose Interface Bus, IEEE-488 protocol
R232- serial communication protocol TX, R, G 3 wires
DAQ- Data Acquisition
ADC – Analog to Digital Converter
DAC – Digital to Analog Converter
I2C - chip protocol pronounce eye square c
SPI - Serial Port Interface
RS484 – serial communication protocol with addressing capability
DUT – Device Under Test

1.6 Organization of Thesis

Chapter 1 covers the software requirements and the methodology used to attain them. Also, I discuss hardware limitations and constraints and review background information on analog-to-digital parameters.

In Chapter 2 performance metrics of ADC is discussed. Both static and dynamic performances are reviewed in details.

In Chapter 3 a review of the analysis application is discuss. I explain how to calculate and define the signal-to-noise ration, signal-to-distortion ratio, signal-to-noise plus distortion, and signal-to-peak noise.

In Chapter 4 a general description of analog-to-digital family of chips are presented. I design a solution to the problem using Unified Model Language Methodology. I discuss the microcontroller code and the different testing environment.

Chapter 5 is the implementation phase of the solution. I describe the development environment for both application and microcontroller code. I describe event driven programming and the data structures used in the solution. Graphical User Interfaces of the application are displayed. Both instructions on how to use the application and description of objects on the panel are given.

1.7. Background

In the following section, I explain the basic of signal acquisition, how analog to digital converter operate, and some fundamental concepts of ADC. Signal acquisition is the process of converting a physical phenomenon into data that a computer can use. [4] A transducer is used to convert a measurement of a physical phenomenon into an electrical signal. [5] Physical phenomena can be temperature, force, sound and light. Some examples of transducers are thermocouples used to measure temperature, photoconductive cells to measure light, microphones to measure sound, and load cells to measure force and pressure. [6] The electrical signal from the transducer can be of two types digital or analog.

Most physical phenomena are analog. The information provided in an analog signal is its level, shape, and frequency. Measuring the level of analog signal is measuring its voltage level. Measuring the shape of a signal can provide information about the peak values, slope or integration. To extract frequency information from an analog signal requires that the signal be Fourier Transform into the frequency domain from the time domain. [7]

A digital signal has only two possible states ON and OFF. Digital signal is TTL (Transistor to Transistor Logic). There are only two aspects of a digital signal measured state and rate. An example of digital signal is the encoded signal of a motor spinning.

Doing complex analysis with a computer on a signal requires that the signal be digitized. Digitization is accomplished through an ADC. The ADC converts an analog signal into 0s and 1s into a word which is an approximate representation of the magnitude of the input signal. An ADC continuously maps the analog signal into discrete steps that are represented by digital codes. Each discrete step represents a fixed value of the voltage reference used. Some common characteristics of ADC are resolution, range, amplification, and code width.

1.7.1 Resolution

Resolution is the number of bits used to represent an analog signal. [8] One can look at resolution like the markings on a ruler. The more marks on a ruler, the more precise the measurements are. The higher the resolution (the more bits) an ADC has, the greater the number of divisions used to represent a range. Thus, the smaller a detectable change can be converted. A 3 bit ADC divides the range into 2^3 or eight divisions. The binary code goes from 000 to 111 to represent each division. The ADC converts each measurement of the analog signal to one of the eight divisions. The figure below shows the difference between a 3 bit ADC and 16 bit ADC used to convert a 100 Hz sine wave sampled at 1 KHz with 1000 samples taken. A 16 bit ADC has 2^{16} (65536) divisions. 16 bit ADC is much more accurate representation of the sine wave.

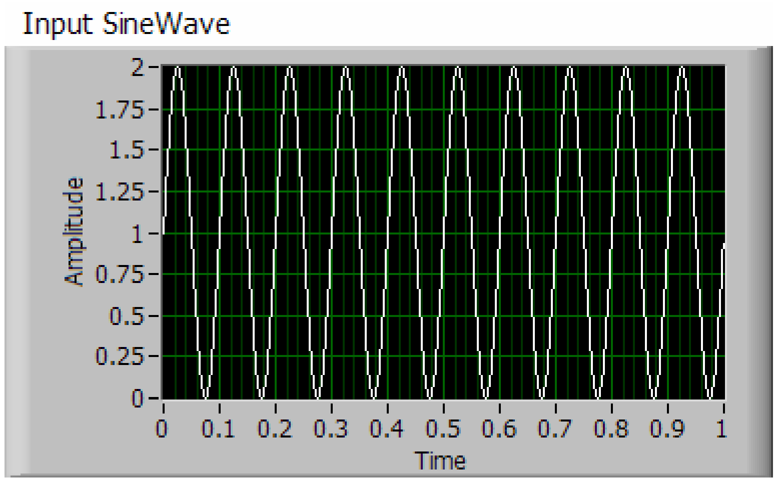


FIGURE 2 INPUT SIGNAL SINE WAVE 100 HZ

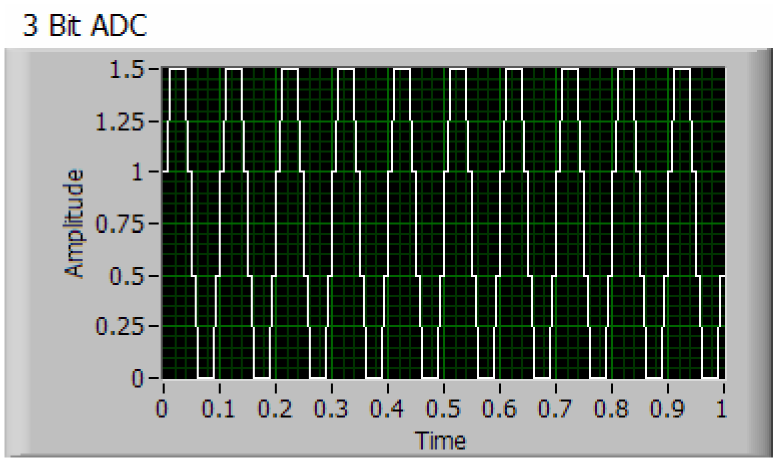


FIGURE 3 ADC 3 BIT CONVERSION OF SINE WAVE

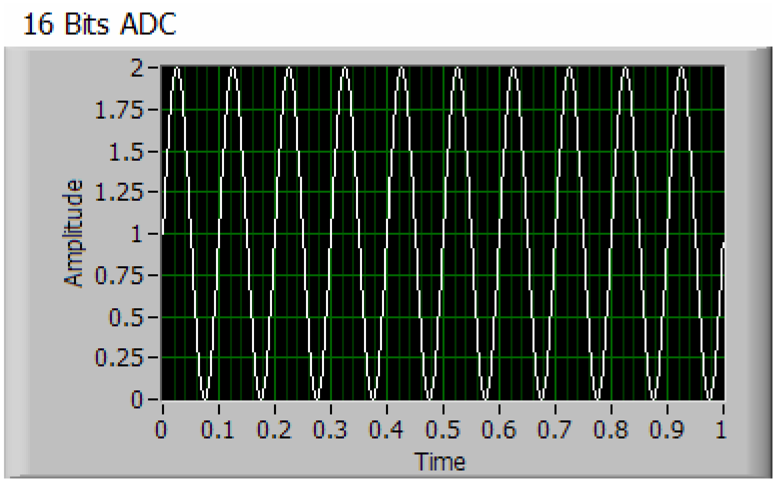


FIGURE 4 ADC 16 BITS CONVERSION OF 100 HZ SINE WAVE

1.7.2 Range

Range is the minimum and maximum analog signal that an ADC can quantize. Typical, ranges are 0V to 10V (unipolar) or -10V to 10V (bipolar). For better accuracy the range of the ADC should have the same polarity as the signal. For example, if the input signals to an ADC is a unipolar value between 0 and 10 volts and the range of the 3 bits ADC is set to 0 to 10 volts. All eight binary codes are then used to digitize the signal. Each division is a multiple of 1.25 volts. If the ADC is set to bipolar mode from -10 to 10 volts, there are only four divisions used to digitize the positive signal. Each division is now a multiple of 2.5 volts. [9]

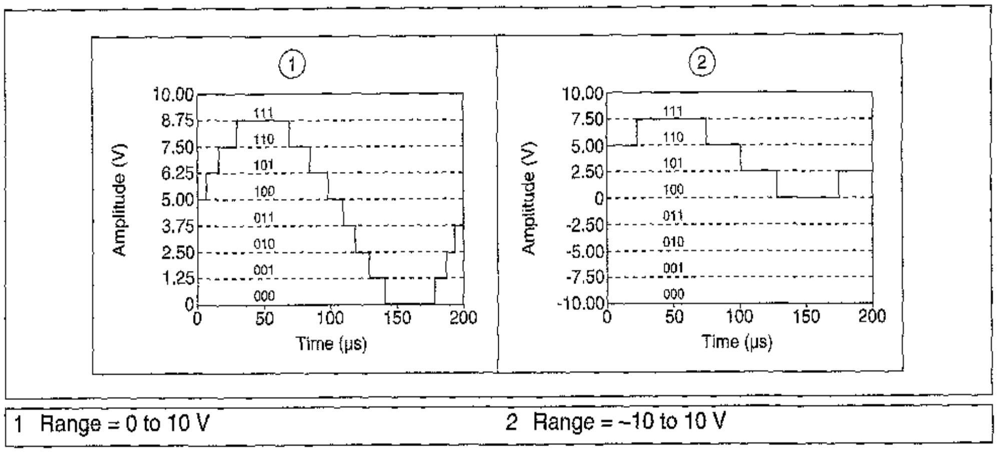


FIGURE 5 RANGE (0-10)V AND (-10 TO +10)V

1.7.3 Amplification

Amplification is the act of amplifying the signal. For the best result the signal is amplified before digitization. By amplifying the signal it effectively decreases the input range of an ADC. This allows the ADC to use the maximum number of digital divisions. For example, if the signal from the transducer is between 0 and 5 V. It is connected to a 3-bit ADC with a range of 0 to 10V. With a gain = 1 or no amplification, there are four divisions used to quantize the signal out of a possible eight divisions. Change the gain to 2, and the input voltage is now scaled between 0 and 10V. All eight codes can be used to digitize the signal. In summary, the range, resolution, and amplification determine the smallest detectable change that an ADC can quantize.

1.7.4 Code Width

Code width is the smallest change that a system can detect in a signal. The code width is calculated with the following equation:

$$code_{width} = \frac{voltage_{ranges}}{amplification \times 2^{bits}}$$

EQUATION 1 CODE WIDTH

Signal representation is directly correlated to code width. The smaller the code width is the more accurate the signal representation. From Equation 1.1 the following axiom can be proven:

- Larger resolution = smaller code width that results in a more accurate representation of the signal
- Larger amplification = smaller code width that results in a more accurate representation of the signal
- Larger range = larger code width resulting in less accurate representation of the signal.

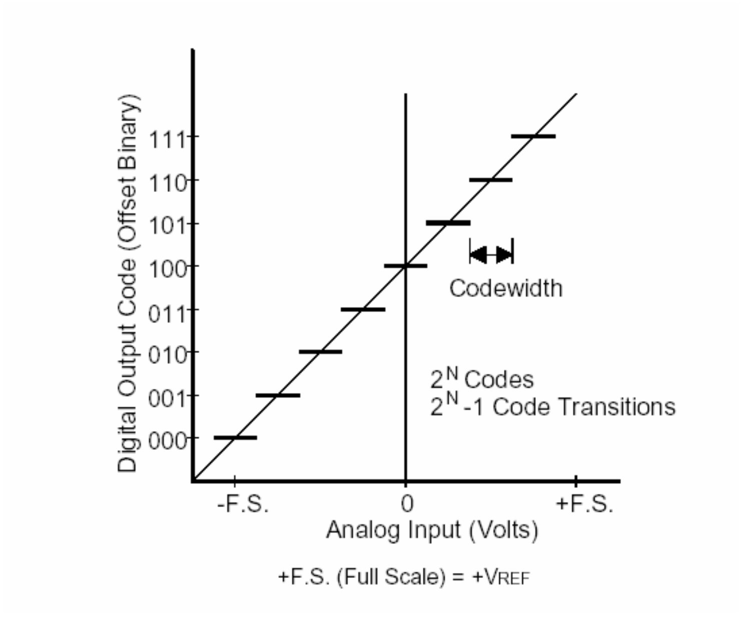


FIGURE 6 ADC 3-BITS CODE WIDTH AND TRANSITIONS

If in Figure 1.6 there is a 12 bit ADC, the voltage range is between -5 to +5 V and gain = 1. [6] The ideal code width is 2.441 mV. Any signal between 0 and 2.441mv will be encoded as 000. Any signal greater then 2.441 mV but less than 4.882 mV will be encoded as 001 and so on. The plot also shows that there are 2^N codes and 2^N -1 transition. The transitions are represented by the linear line between the steps. The center of one of the codes is defined as zero, which means that a bipolar conversion will have one fewer code on half of the transfer function than the other. This also means that at full-scale, the output code is described at least 1 LSB (Least Significant Digit) less than the voltage reference because of the zero code. In Table 1 the actual code width is calculated for different bit size ADC for a full-scale value = ± 3V. 1 count or LSB can be looked at as the code width.

$$\frac{6Volts}{2^N Codes}$$

EQUATION 2 IDEAL CODE WIDTH CALCULATION

Table 1 CALCULATED LSB VALUES FOR DIFFERENT RESOLUTIONS

Analog-to-Digital Quantization of Full Scale ± 3V				
N	12	16	20	24
1 LSB	1.46mV	91.5μV	5.7μV	0.36μV

Table 2 shows the number of codes calculated from 2^N and the resolution is the code width equation with the range being 1.

Table 2 IDEAL RESOLUTION

Ideal ADC Measurement and Resolution		
N Bits	# of Codes	Resolution
12	4096	244 ppm
16	65536	15 ppm
20	1,048,576	0.95 ppm
24	16,777,216	0.06 ppm

1.7.5 Conversion Errors

An ADC is a quantizing device. There is always quantization error even in an ideal ADC. When a signal has been digitized, the digital codes representing the signal can actual differ by as much ± ½ LSB (code width). Figure 6 shows the quantization error being plotted per code width. The best that an ideal ADC can do in representing the signal verses quantization noise is calculated by the following equation. N is the number of ADC bits. [11]

$$SNR = 6.02N + 1.76dB$$

EQUATION 3 SIGNAL TO NOISE RATIO

The signal to noise ratio (SNR) defines the full scale root mean square of the sine wave to the root mean square of the quantization noise. [11]

Table 3 IDEAL SIGNAL-TO-NOISE

Ideal Signal to Noise Ratio	
N Bits	S/N(dB)
12	74
16	98
20	122
24	146

Table 3 shows the best possible signal that an analog-to-digital converter can produce with the given bits of ADC.

The step-size of a real world ADC can be greater or smaller then the ideal quantization step size. The changes in step size introduce an additional error called the differential nonlinearity (DNL). [12] DNL is the difference between the actual sizes of the code versus the ideal. SNR decreases with an increase in the DNL. The variation in code size is a function of the matching accuracy of the elements that compose the converter. Large mismatches in the ADC electrical converting elements can cause short or wide codes or even cause code to be missing. These variations can be caused by random environmental changes or parasitic noises in the system itself. Figure 7 is a plot of the differential nonlinearity.

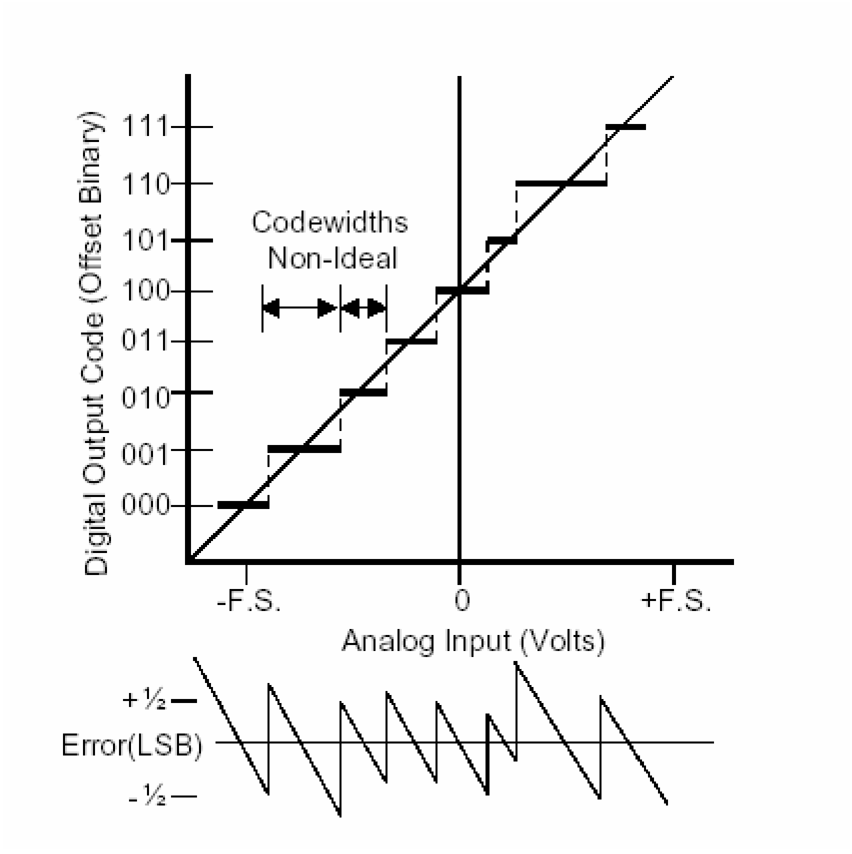


FIGURE 7 DIFFERENTIAL NONLINEARITY

Integral Nonlinearity (INL) is a measure of the linearity of the entire transfer function of the ADC. A straight line is drawn between the codes at each end of the transfer function. Integral nonlinearity is the furthest distance from the center point of the line and the code. [13] Another method of calculating INL is to put a full-scale low distortion sine wave into the converter and do an FFT (Fast Fourier Transform) to calculate the spectral density characteristics converter. [14]

Signal/noise and Signal/(noise plus distortion) can be calculated. Figure 5 shows the integral nonlinearity of the converter.

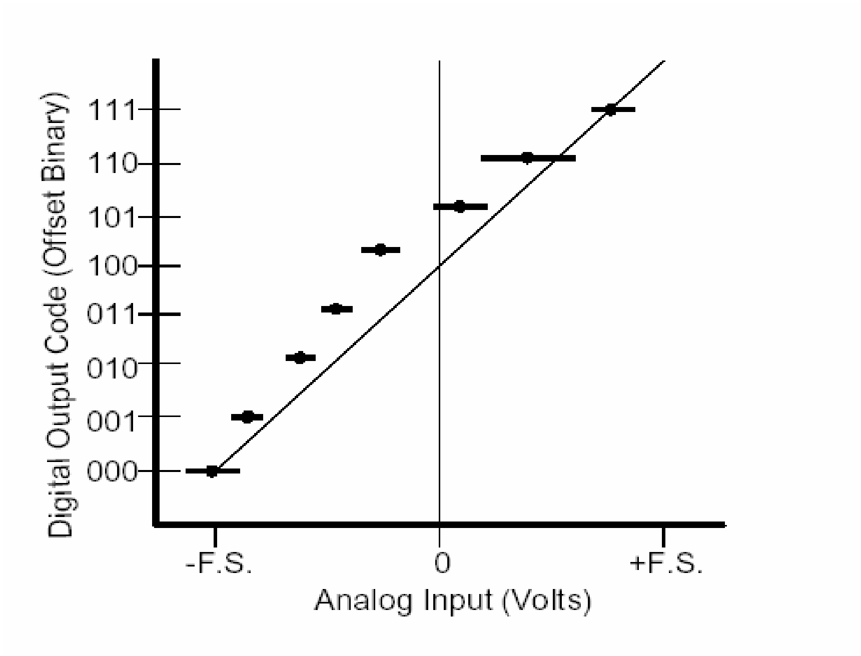


FIGURE 8 INTEGRAL NONLINEARITY

Offset error is the shift of the zero point in the code. This is the code generated when the voltage input into the ADC is zero. It is determined from the mean of histogram of codes. This calculation will be discussed later in this chapter. Figure 9 is an example of offset. [15]

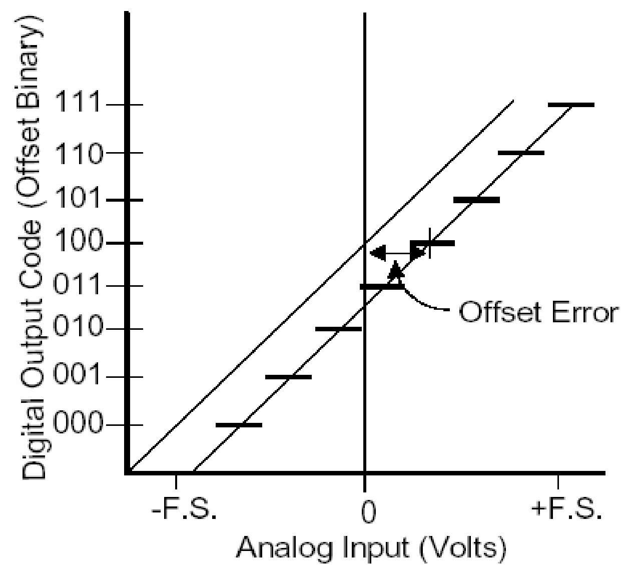


FIGURE 9 OFFSET ERROR

The gain error is the change in the slope of the converter transfer function. It is the difference between a given code and a line being drawn from the origin through the 0 volt code value. Figure 7 shows the gain error calculation. [11]

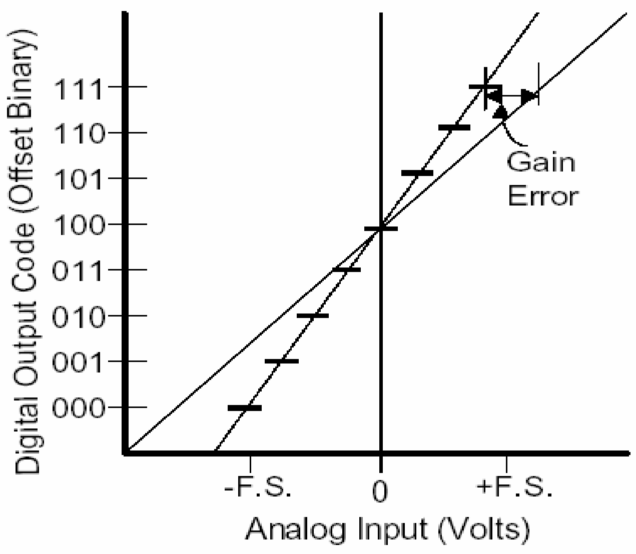


FIGURE 10 GAIN ERRORS

Another cause of conversion error is aliasing. Aliasing results when the sample rate is below the Nyquist Theorem for an incoming signal. A signal x(t) in the time domain is sampled every Δt seconds. This time interval is called the sampling interval or sample period. The reciprocal 1/Δt is the sampling frequency. It is in unit samples/second. Each discrete value (binary code) of signal x(t) at time t = 0, Δt, 2Δt, 3Δt, etc., is a sample. [16] The signal x(t) is now represented by discrete signals. This is the definition of a digital representation of a signal.

$$x(t) = x(0), x(\Delta t), x(2\Delta t), x(3\Delta t),..., x(k\Delta t)$$

EQUATION 4 ANALOG TO DISCRETE SIGNAL REPRESENTATION

The sample rate is the speed at which a measurement device samples an incoming signal and generates an output signal, in this case, binary code. The faster the sample rate the better the representation of the original signal. Nyquist Theorem states that to accurately display a continuous signal discretely, one must sample at least twice the signal's highest frequency component. Figure 11 below is a graph showing an aliased sample signal. The 'x' represents the discrete signal generated by the converter. The bottom plot shows the ADC plot of the signal overlaid on the original signal. [17]

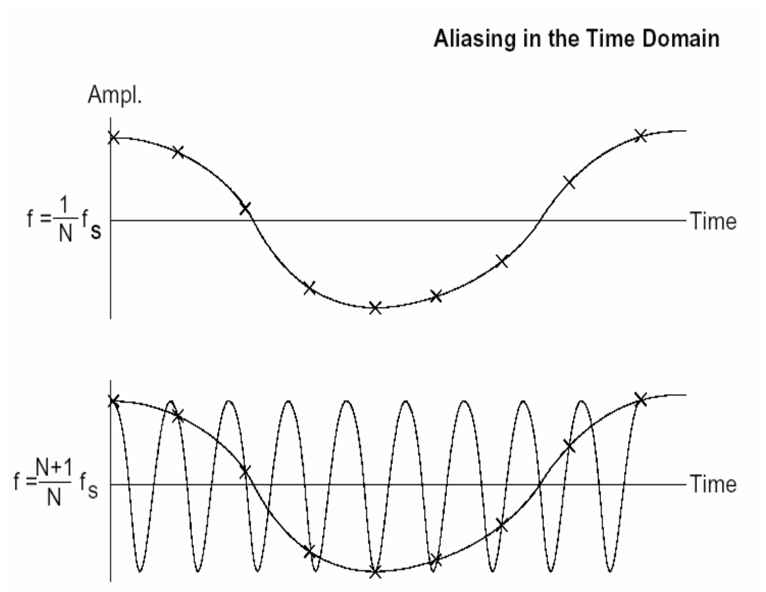


FIGURE 11 ALIAS TIME DOMAIN SIGNAL

In the frequency domain, aliasing appears as non-existing frequencies below the Nyquist frequency. For example, a signal composed of four frequencies 25 Hz, 70 Hz, 160 Hz, and 510 Hz. If the sampling frequency is 100 Hz, the Nyquist frequency is (fs = 50 Hz). The signal below the Nyquist frequency appears correctly, but the 70 Hz signal appears as 30 Hz signal below Nyquist and so on. Alias frequencies generated are calculated with the following formula:

Alias f = abs(closet integer multiple of sampling frequency – Input Frequency). [18]

EQUATION 5 ALIAS FREQUENCY GENERATED

Figure 12 shows the alias frequency plotted. The calculations are:

- Alias F2 = |100 -70| = 30 Hz ,
- Alias F3 = |(2)*100 -160 | = 40 Hz
- Alias F4 = |(5) * 100 – 510| = 10 Hz

There are two ways to get rid of aliasing, filtering and/or increasing sample rate. Sample rate increase is the simplest and easiest method.

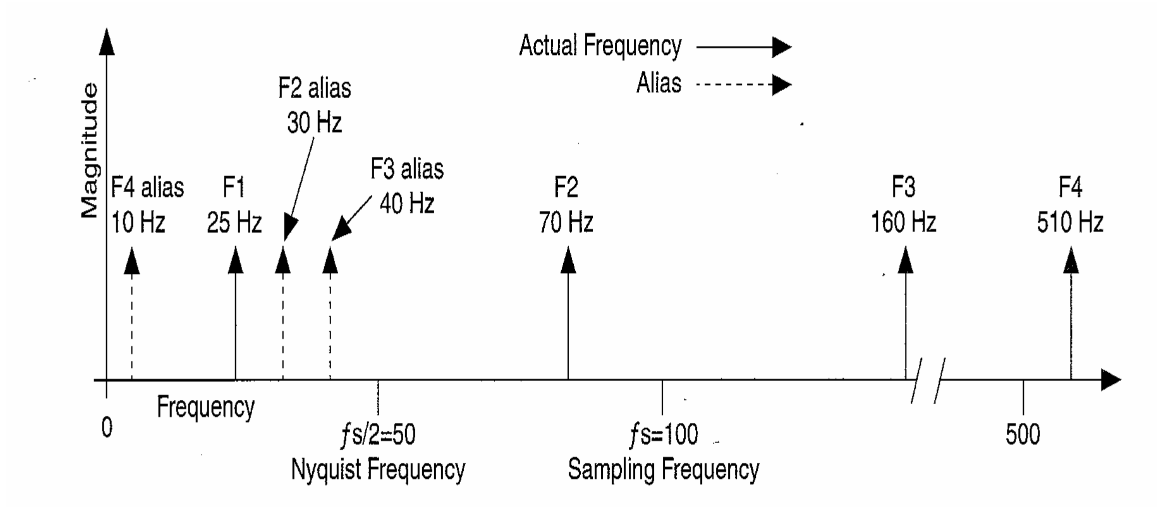


FIGURE 12 ALIASING IN THE FREQUENCY DOMAIN

CHAPTER 2

PERFORMANCE METRICS FOR ADC

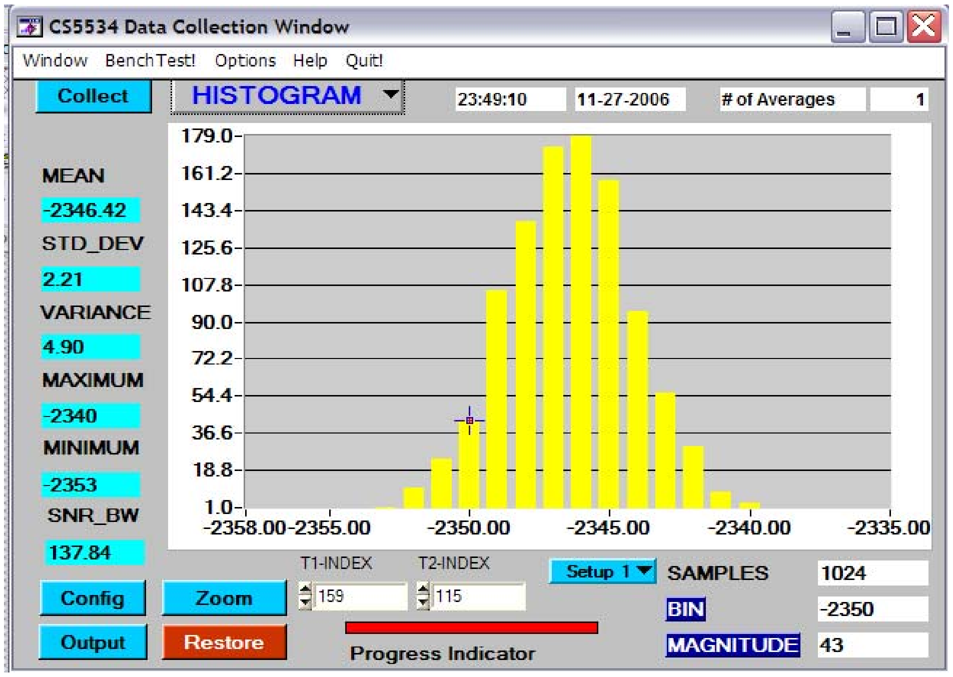
INTRODUCTION

To measure the quality of an ADC, there are basically three techniques applied to the analog signal. First, the time domain signal is plotted into a histogram. Second, the signal is converted from the time domain to the frequency domain with Fast Fourier Transforms (FFT). Third, both histograms and FFT are used to analyze the signal. Histograms are used to quantify the DC accuracy or static performance. They can generate information about offsets and the low level noise. FFT are used to measure the dynamic performance characteristics like linearity (INL discussed above) of converter, and synchronous noise clock feed (spurious beeps) in a signal. [19] Both histogram and FFT can determine random noise. Information from both techniques can be used in troubleshooting since both tests use the same data set. For example, noise can be classified as asynchronous or synchronous. [20]

2.1 Static Performance

2.1.1 Histogram Analysis

Analog signals that do not vary or varies little over time are static signals. Some examples of static measurements are weights, pressure, and temperature. Static measurements can be low-level signals that require high resolutions. A histogram is the tabulation of frequency occurrence in a signal that is represented by rectangles. The area of a rectangle is proportional to the occurrences. The information from a histogram quantifies the error and noise associated with the conversion. Physically, a static signal is applied to the input of the ADC. Several conversions are done by the ADC on the non-changing signal. If the ADC is ideal, all the samples collected would have the same value or code. Therefore the histogram plot would be one bin, where the x-axis would be the code returned and the y-axis would equal the number of samples collected. From previous discussion there is no such thing as an ideal analog-to-digital converter because there is always quantization error (noise). With noise added to the conversion process, the values collected are going to vary as a function of the amount of noise. The histogram of non-ideal ADC would have several codes for a static input value. Figure 13 shows a non-ideal ADC histogram. The plot to the left is a histogram that is noise free. The plot to the right is a histogram with noise added. For a given, input the output could be one of ten values.



23:49:10 11-27-2006 # of Averages 1

MEAN -2346.42
STD_DEV 2.21
VARIANCE 4.90
MAXIMUM -2340
MINIMUM -2353
SNR_BW 137.84

T1-INDEX 159
T2-INDEX 115

SAMPLES 1024
BIN -2350
MAGNITUDE 43

FIGURE 13 NON-IDEAL ADC HISTOGRAM

2.1.2 Gaussian

Random electrical noise has been shown to have a Gaussian distribution. [20] The Gaussian's probability density function (PDF), is represented by a normal or bell shaped curve. It is a continuous curve that is used to determine the mean and the standard deviation. The Gaussian PDF is described by the following equations:

$$p(x) = \frac{n}{\sigma\sqrt{2\pi}} e^{-(X-\mu)/2\sigma^2} \text{ [21]}$$

EQUATION 6 GAUSSIAN PROBABILITY DENSITY

The mean and the standard deviation are given by the following equations equation 7 and equation 8 below respectively:[22]

$$\mu = \frac{1}{n}\sum_{i=1}^{n} X_i$$

EQUATION 7 MEAN

$$\sigma^2 = \frac{\sum_{i=1}^{n}(X_i - \mu)^2}{n-1}$$

EQUATION 8 STANDARD DEVIATION OF DIGITIZED SIGNAL

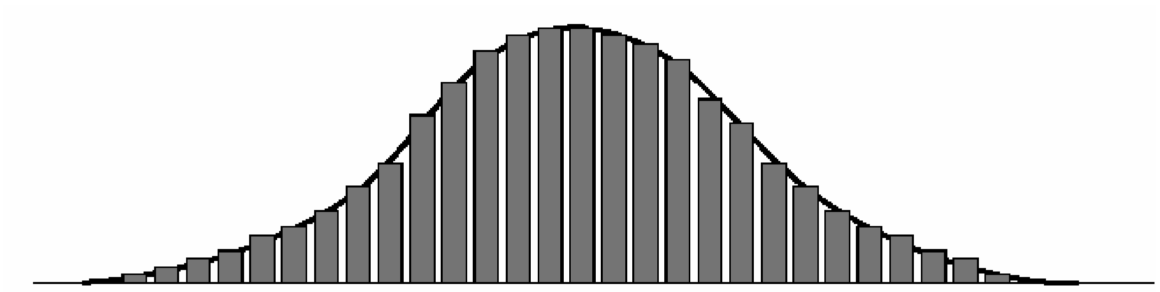


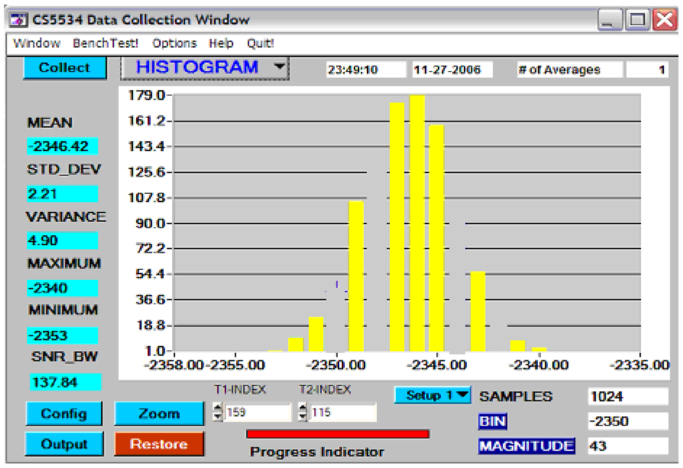
FIGURE 14 GAUSSIAN NOISE AND PDF

The information collected from the histogram is used to calculate the mean and standard deviation. In Equation 7 and 8 the Xi value is the value outputted from the ADC. “n” is the number of samples taken. In Figure 14 the probability density function is plotted with the histogram and shows a good correlation between the histogram and the PDF curve. This means that the bell curve is a good model of the conversion data collected from the ADC. [23] By using the PDF, the performance of the ADC can be quantified. The mean, which is the average value collected, is the offset of the ADC. The variance is a measure of the uncertainty or noise in the system. It describes how much the value varies from the mean outputted by the ADC. The square root of the variance is the standard deviation. The standard deviation is the root mean square of the noise, also known as the rms noise. [24] From the rms noise, the peak to peak noise can be determined. For example, if the input to the ADC is grounded resulting in a zero value, the expected mean of all the converted value would zero. The offset error is the difference between the expected and actual mean calculated. From Figure 13 the mean is not zero. The error can be caused by electrical and quantization noise. From the sample data the rms noise is calculated from the standard deviation. The peak-to- peak noise is the confidence interval statistics. [25] The question answered by the peak-to- peak noise is: “How confident are you that the signal is within the sample set?” To use 99.9% of all the values collected from the ADC, the standard deviation is multiplied by 6.06 for a normal distribution. The more samples collected by the ADC and analyze the better the characterization of the ADC's behavior. To better understand what has been presented, several examples have been included. Figure 13 shows is the plot from a 24 bit ADC with the gain of one. The code width is calculated from +/- range / 2^N, (N is the number of bits). The count is the bin number. The count multiplied by the code width gives the voltage value. For example, the offset voltage value for -2346 codes is -700 μV. Figure 13 is calculated with 1024 samples. This calculation could be repeated with the ADC at full scale to measure the gain error. [26] The standard deviation should remain constant. The small difference is the result of sampling error.

How many samples to take? The number of samples to take is a function of the confidence interval, degree of accuracy, and distribution variables. [27] Confidence, is basically the degree of certainty that the estimate is within a certain range. The degree of accuracy is how accurate you want to represent the real world signal. For example acquiring 1024 samples is more accurate representation of ADC conversion behavior then only 10 samples. If the distribution varies significantly then many samples are necessary to determine the ADC behavior.

2.1.3 DNL Affect on Histogram

Histogram plots are drawn with the assumption that the uncertainty or noise is random. If the noise is truly random, then the histograms sample set models a bell-shaped curve. When the differential nonlinearity (DNL) is high, it distorts the distribution of random noise. [28] Wide code (code covering several voltages greater then the code width), have a higher probability of occurring then narrow code. This error can result in complete bins being absent from the histogram, which means that codes are missing. This can result in unreliable statistics. Figure 15 is example of histogram having large number for the DNL.



23:49:10 11-27-2006 # of Averages 1

MEAN -2346.42
STD_DEV 2.21
VARIANCE 4.90
MAXIMUM -2340
MINIMUM -2353
SNR_BW 137.84

T1-INDEX 159 T2-INDEX 115

SAMPLES 1024
BIN -2350
MAGNITUDE 43

FIGURE 15 HIGH DNL AFFECT ON HISTOGRAM

2.1.4 Averaging

Averaging requires that the ADC have a good DNL value. Averaging is a method to increase the bit resolution and decrease the amount of uncertainty caused by noise in a signal. [29] For example, the analog input is set to 1.45 counts, (voltage = counts * code width). The digital output from the Analog-to-Digital Converter (ADC) is the following { 1,2,3, 1,1,2,1,2,1,0,2,1}. If no noise is present, the output for the ADC would be only one value, 1.45. Since there is noise, the count varies between 0 and 3. If only the first value is taken, the count would be 1. If the first four samples are averaged, the count would be 1.75. If the first nine samples are averaged, the count would be 1.556. And if all twelve samples average, the count is 1.417 which is closer to the actual value of 1.45 counts. Averaging increases the precision of the conversion. The mode for the ADC output is one with a frequency of six.

How does averaging improve the resolution? From the previous twelve ADC outputs the following statistical characteristics are calculated in counts.

- Mean = 1.417
- Variance = 0.629
- Standard deviation = 0.793

To attain a 95% occurrence of all converted values the normal distribution states that the standard deviation must be multiplied by ±1.96. If one sample is used, then the variation in the actual value would be ± (1.96*0.793) or better yet ±1.554

counts. If the first conversion is used from above with a count value of 1, then there is a 95% certainty that the value is between -0.554 and 2.554. Averaging reduces the standard deviation by one over the square root of the number of samples used in the averaging data. [29] For example, the above 12 samples were used to average the data. The count was 1.417 and the uncertainty is ±0.449 counts instead of ±1.554 counts.

2.1.5 Flicker Free Bits

Flicker free bits are the number of bits that do not have any flicker. [30] It is the actual resolution of the ADC including system noise, thermal noise, quantization noise, and any spurious noises. The signal-to-noise ratio equals:

$$SNR = 20\log\left({}^{noise}\!\big/_{fullscale\_input} \right)$$

EQUATION 9 SNR CALCULATION WITH NOISES

Also, SNR is given by the following from above: SNR = 6.02N +1.76 for quantization noise only. Using Equation 9, noise is equal to the peak-to-peak noise, which is 6.6 x rms noise. the number 6.6 gives a confidence interval of 99.9%. RMS noise is just the standard deviation. For better understanding, here is an example I calculated. ADC has rms noise equals 1.25 uV. The analog input range is ±2.56 V. Using Equation 8 with peak-to-peak noise value, the SNR = 20 log ((6.6 x 1.25E-6)/(2 x 2.56)) = -115.85db.

The peak-to-peak resolution is

$$115.85 = 6.02N + 1.76 \Rightarrow N = (115.85-1.76)/6.02 = 19 \text{ Bits.}$$

Some companies use the effective resolution rather than the peak-to-peak resolution. The effective resolution is calculated with the rms noise only. The signal to noise ratio would then be

$$20 \log ((1.25E-6)/(2*2.56)) = -132.25\text{dB}$$

This leads to an effective resolution of

$$132.25 = 6.02N + 1.76 \Rightarrow N = (132.25-1.76)/6.02 = 21.7\text{Bits}$$

Effective resolution has 2.7 more bits then peak-to-peak resolution. The effective resolution does not show the number of bits that flicker. The peak-to-peak resolution gives a better indication of true performance since it shows the number of bits that do not flicker.

In summary, a device that has an effective resolution of 22 bits has a flicker-free resolution of 22-2.7 = 19.3 bits or 19 bits. From the above calculation if this were a 24 bit ADC, then 19 bits would be noise free in the conversion. This example also shows the importance of averaging. If the standard deviation is reduced by averaging with a factor of ten to 1.25E-7, the number of flicker-free bits with a peak-to-peak resolution would be 22 bits instead of 19 bits.

2.4 Dynamic Performance

Dynamic performance is the characterization of how the conversion function alters the spectrum of the signal transmitted through the system. Spectral analysis is used to decompose the input signal into its frequency components. The time domain signal collected by the ADC is converted into the frequency domain using Fourier Transform. The magnitude of the frequency components is used to determine the signal power at a given frequency. This is the power spectrum plot. The frequency elements also include phase information. For this project, phase information was not needed so it was discarded. The transform process starts at the Analog-to-Digital Converter (ADC). A continuous analog signal is converted to an n-bit binary digital word. The ADC output the digital words at a rate set by the sampling frequency (F_s). The ADC throughput determines the maximum sampling frequency. The conversion from the time domain is done using Fast Fourier Transform (FFT) algorithm. A sample set of data is collected for the FFT. The data set size is expected to be a power of 2 and periodic. The data set size is a function of computer memory and processing throughput, input signal dynamics, and degree of frequency resolution. [31] If the data set is non-periodic, high frequency elements will exist in the frequency domain that do not exist in the input signal. Figure 16 shows analog sample sets. The first sample is periodic and with three sample sets. The second sample is non-periodic and shows the discontinuity that would result in high frequency components.

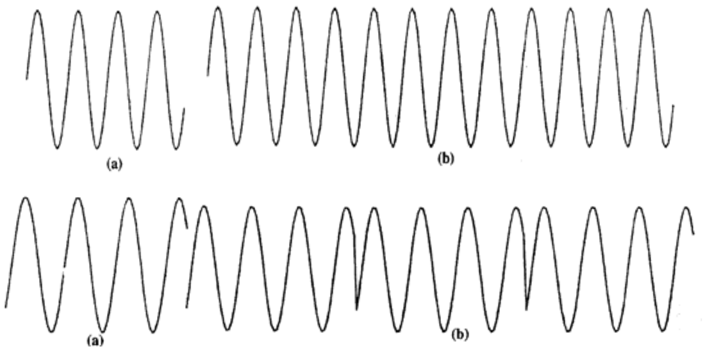


FIGURE 16 PERIODIC AND NON-PERIODIC ANALOG SIGNALS

2.4.1 Windowing

FFT algorithm requires that the signal cycles be in integer multiples and that the number of samples be a power of two. These requirements are difficult to adhere to in a real world signal. A real signal is usually composed of several frequencies making periodicity difficult. The lack of periodicity results in signal discontinuities. This leads to spectral leakage of the signals fundamental. Figure 17 is a graph of the FFT of a perfect sine wave that meets the FFT requirements periodicity and non-periodic signal. The high signal floor around the fundamental of non-periodic signal is spectral leakage. Spectral leakage is where the energy of the fundamental is dispersed from the fundamental reducing the energy of the signal. [32]

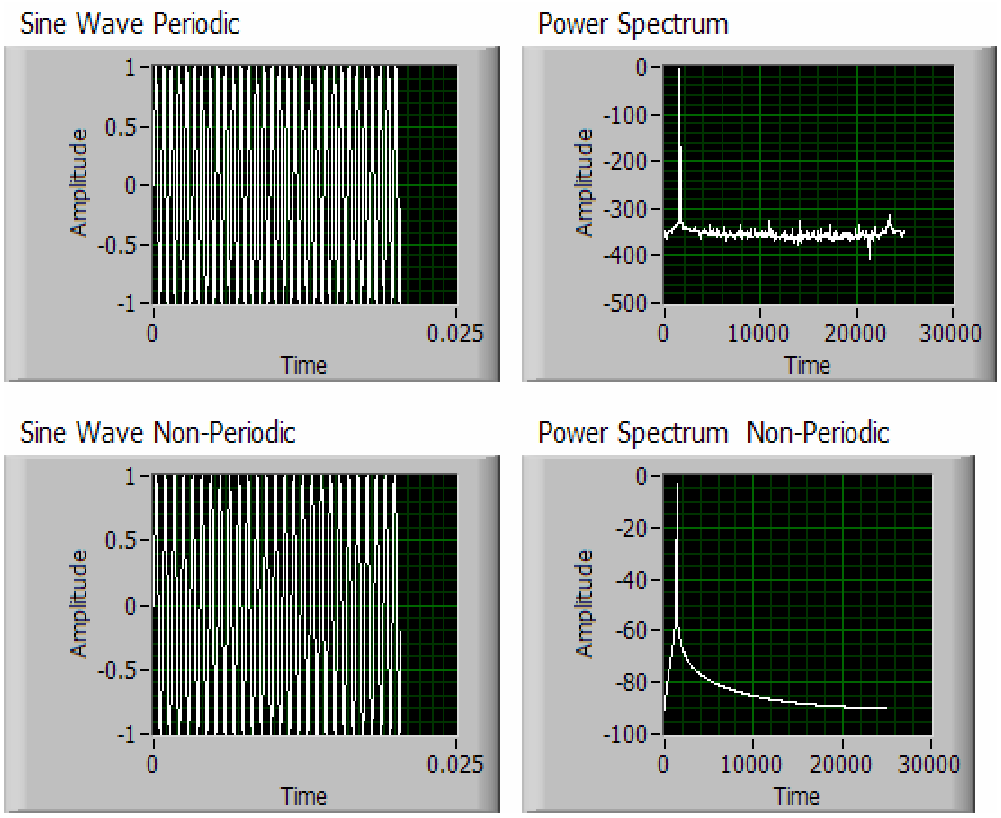


FIGURE 17 FFT PERIODIC AND NON-PERIODIC SIGNAL

Windowing is used to reduce the spectral leakage that results from taking the FFT of a non-periodic and/or dynamic signal. Windowing multiplies the time domain signal by a function that attenuates the amplitude on the ends. This reduces the discontinuity. The windowed data set can be combined without discontinuity. Windowed signal energy is spread to several bins instead of just one bin in the mainlobe. The objective of windowing is to keep the fundamental energy in the mainlobe with very little leakage to the sidelobes. Figure 18 is a plot of a sine wave in the time domain windowed. In the figure, the signal endpoints are attenuated by the windowing functions.

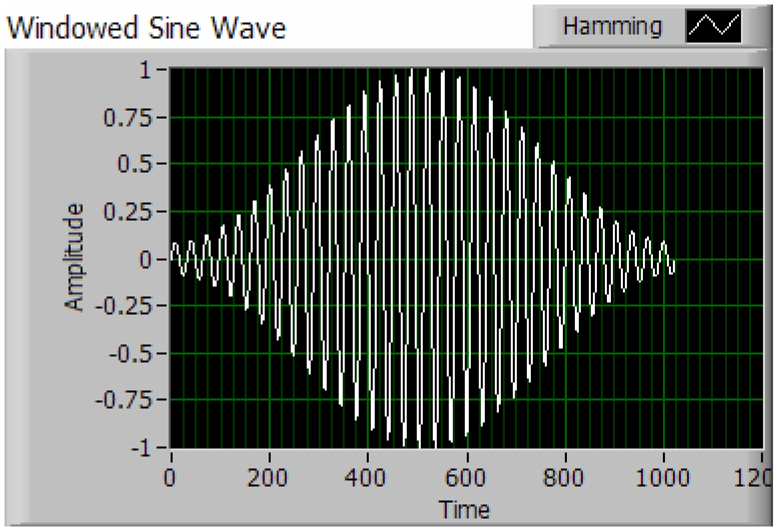


FIGURE 18 SINE WAVE WINDOWED WITH HAMMING

One tradeoff with windowing is the smearing of the input signal among several bins and the leakage in the sidelobe. [33] When an input signal is multiplied by a window, the signal is spread among several bins, smearing the exact frequency. The wider the mainlobe is which includes most of the input signal, the greater the smearing of the frequency. The amount of spectral leakage is directly proportional to the magnitude of the sidelobes. When the sidelobes are greater then the noise floor, the input signal is leaking to frequencies outside the mainlobe. In general, the sidelobes magnitude is inversely proportional to the width of the mainlobe as shown in Figure 20.

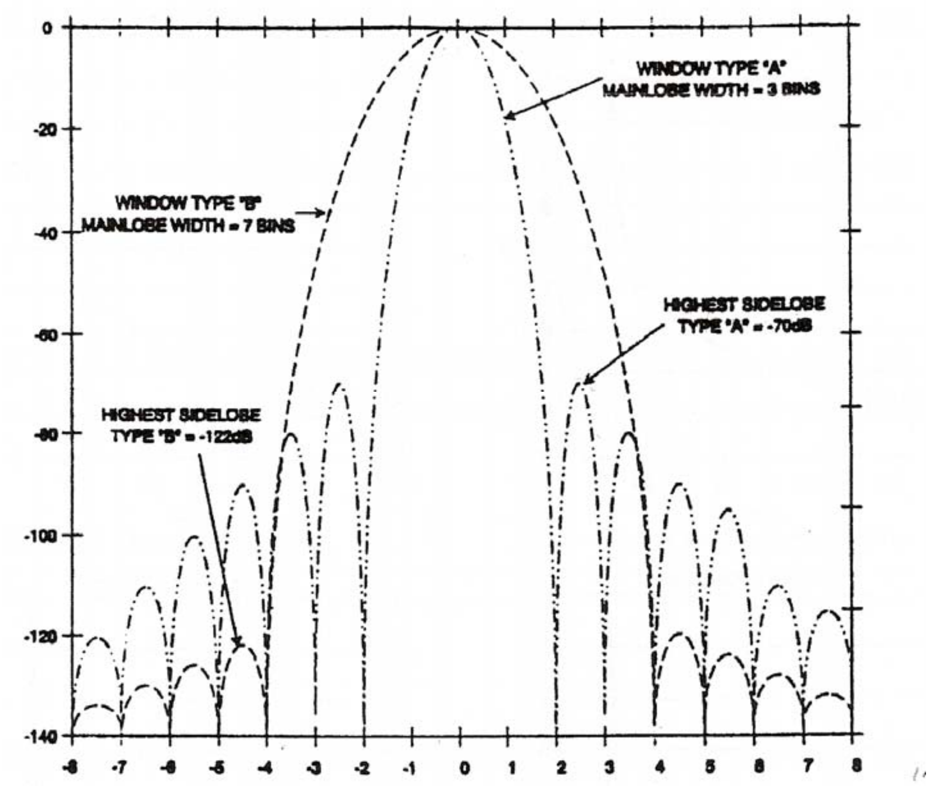


FIGURE 19 MAINLOBE AND SIDELOBE OF WINDOWS

Also, the ability to distinguish between different frequencies components of the input signal is inversely proportional to the width of the mainlobe. [34] In Figure 21 there is a plot of a sine signal composed of two frequencies. One signal has amplitude of 0.001 and a frequency of 73.92. The other signal has amplitude of 1.00 and a frequency of 66.90. The signal is windowed with two different windowing functions “Exact Blackman” and “Flat Top”. From the plot, the “Exact Blackman” windowed signal shows two frequencies while the “Flat Top” windowed signal shows only one frequency. The mainlobe of the “Flat Top” is larger then the mainlobe of the “Exact Blackman”. This is an example of frequency blearing.

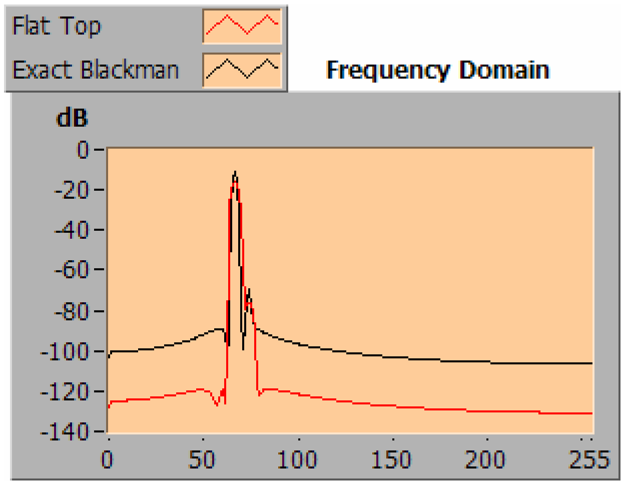


FIGURE 20 FREQUENCIES BLEARING FROM WINDOWING

The smallest frequency that is detectable from a windowed signal is given by the equation below:

$$f = mainlobe\_width * \frac{F_s}{N} \text{ [35]}$$

EQUATION 10 WINDOWING FREQUENCY RESOLUTION

“f” is the frequency. The mainlobe width is given in Table 4 below. Fs is the sampling frequency and N is the number of samples taken. From Equation 10, the frequency resolution can be improved by increasing the number of samples taken. [36]

Table 4 WINDOWS METRICS

Window Type	Mainlobe Width (Bins)	Highest Sidelobe Level (db)
Hanning	5	-32
Blackman	7	-58
Minimum 4-term Blackman-Harris	9	-92
5-term Hody	11	-125
7-term Hody	15	-175

Table 4 shows the Windowing Metrics for different window type. The Hody window was developed by Mr. Hody at company C.L. I included both Hody windows in the "Analysis" application.

Figure 21 shows some of the windowing functions that I implemented in this program. The choice of window function depends on the application, the system performance, and the information required. Windowing metrics used to determine the window to use is the highest sidelobe level, sidelobe fall-off, the equivalent noise band width, the 3db band width, and worst case process loss. [36]

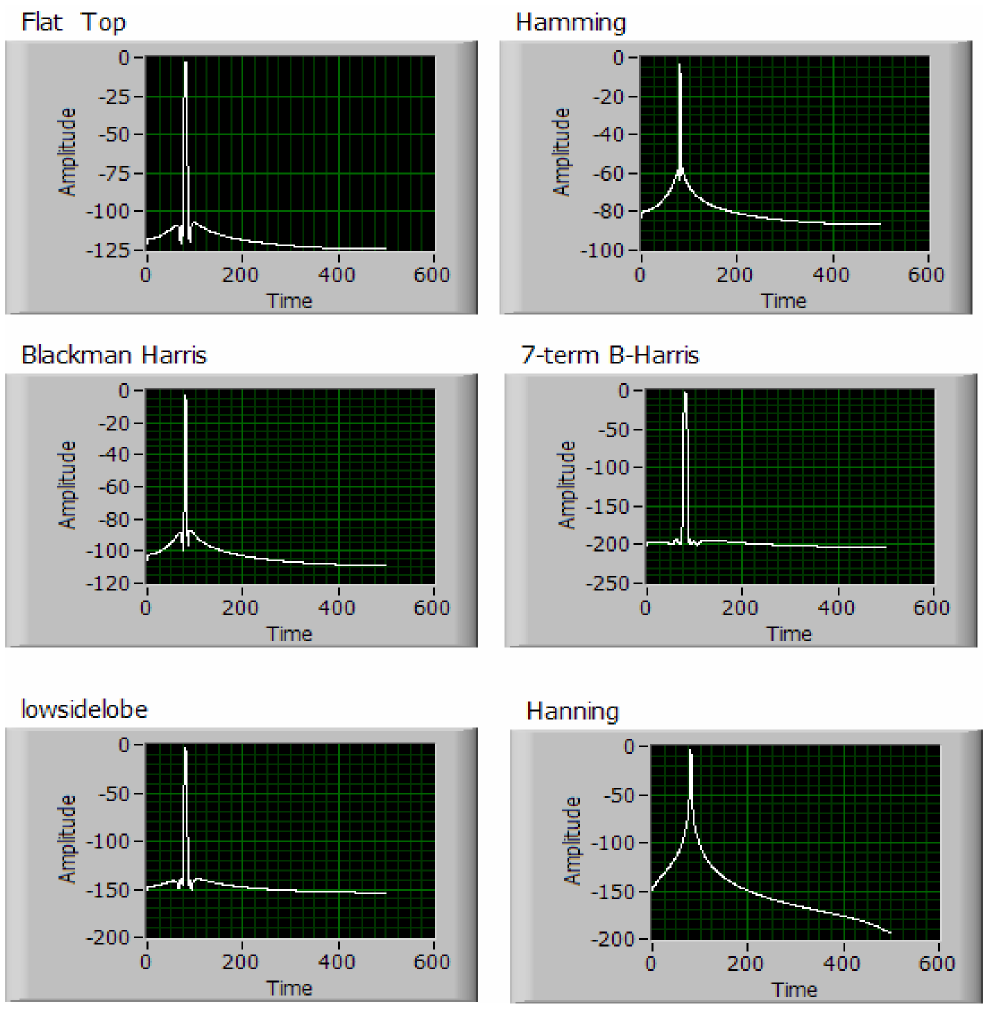


Figure 21 WINDOWS SINE WAVE PLOT

2.4.2 Signal Analysis Statistics

There are four key performance measurements that are used to characterize the linearity of the system and the noise characteristics from the power spectrum. They have been discussed above so they will only be mentioned here. They are:

1. Signal-to-Noise Ratio (SNR)
2. Signal-to-Noise and Distortion (SINAD)
3. Signal-to-Distortion (SD)
4. Signal-to-Peak-Noise (SPN)

These are used for benchmarking and troubleshooting performance issues. I used a flow charts diagram for the pseudo-code and for the analysis algorithm in following chapter.

CHAPTER 3

ANALYSIS APPLICATION

The following equations are used to calculate the signal to noise ratios: [37]

$$SNR = 10\log\left(\frac{Fundamental\_Power}{NoisePower}\right)$$

EQUATION 11 SIGNAL-TO-NOISE RATIO

$$SINAD = 10\log\left(\frac{Fundamental\_Power}{NoisePower + HarmonicPower}\right)$$

EQUATION 12 SIGNAL-TO-NOISE PLUS DISTORTION

$$SDR = 10\log\left(\frac{Fundamental\_Power}{HarmonicPower}\right)$$

EQUATION 13 SIGNAL-TO-DISTORTION RATIO

$$SPN = 10\log\left(\frac{Fundamental\_Power}{PeakNoisePower \vee (2ndHarmonic + 8binsofnoise)}\right)$$

EQUATION 14 SIGNAL-TO-PEAK NOISE

Figure 22 is a flow chart describing the basic steps to calculate the dynamic performance statistics. Each basic state has it own unique flow charting and diagram that I used in implementing the analysis program.

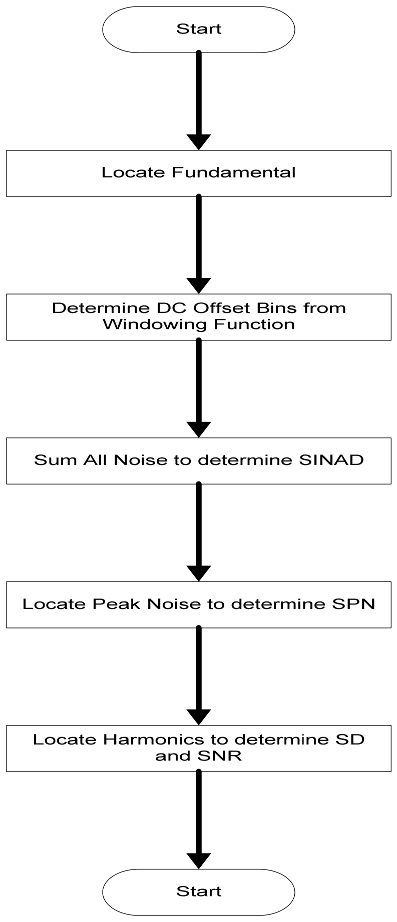

Start
Locate Fundamental
Determine DC Offset Bins from Windowing Function
Sum All Noise to determine SINAD
Locate Peak Noise to determine SPN
Locate Harmonics to determine SD and SNR
Start

FIGURE 22 BASIC DYNAMIC PERFORMANCES

To calculate the signal noise metrics one must first determine how many frequencies are contained in the DC limits of the signal and how many frequencies are contained in the fundamental signal. [38] These questions are a function of the windowing type. For each window, the following coefficients are assigned: ndt, slfund, sldc, and dclim. For example, for the 7-Hody term, ndt is 6, slfund = 0, sldc = 7, and dclim = ndt+sldc. DC power is the sum of the frequencies starting at zero on the x-axis of the power spectrum to the dclim. The fundamental power is the sum of plus and minus the ndt of the maximum signal after the dclim. This is explained further below.

The following is a schematic and flow chart that I developed to write the algorithm to calculate the SNR of a signal. [39] The fundamental energy of the signal is in black.

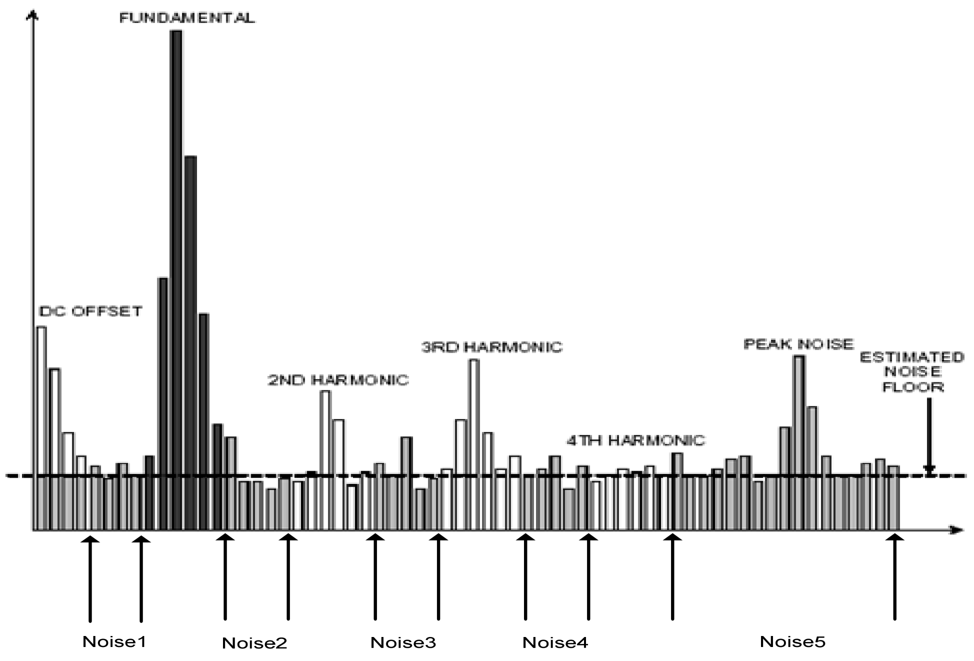


FIGURE 23 POWER SPECTRUM OF SIGNAL

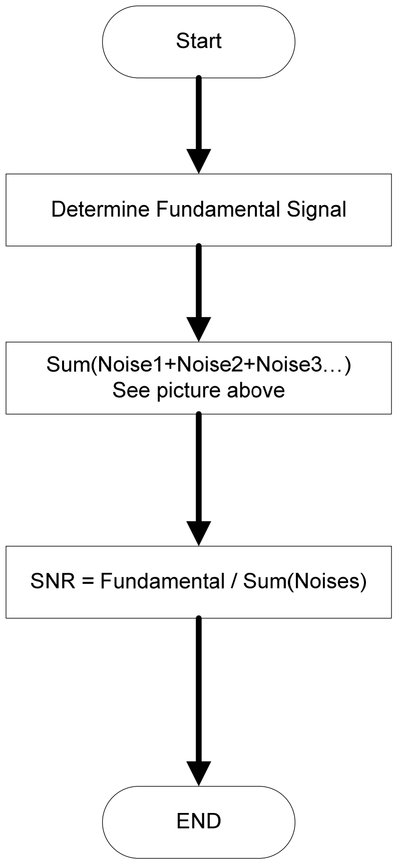

Start
Determine Fundamental Signal
Sum(Noise1+Noise2+Noise3…)
See picture above
SNR = Fundamental / Sum(Noises)
END

FIGURE 24 SNR FLOW CHART

For each of the frequencies contained in the DC region of the signal, the average noise for the signal is used in the sum of noises.

The following is used to calculate the SDR (signal to noise plus distortion). [40]

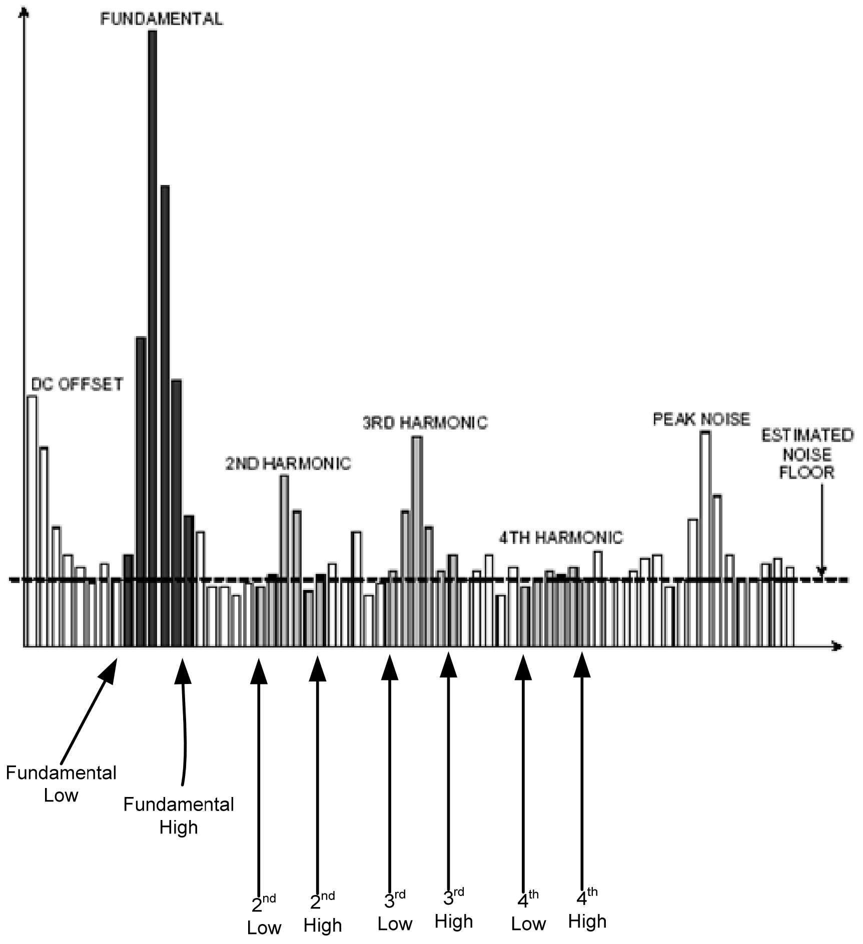


FIGURE 25 SDR DIAGRAM

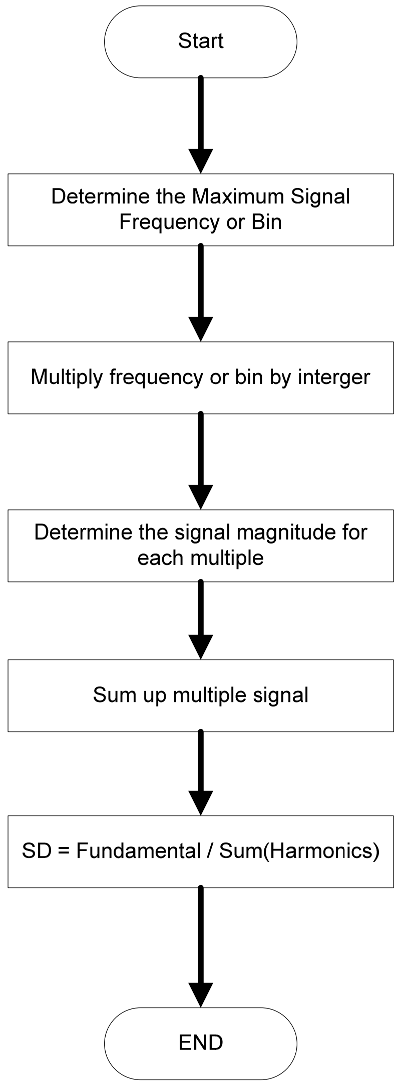
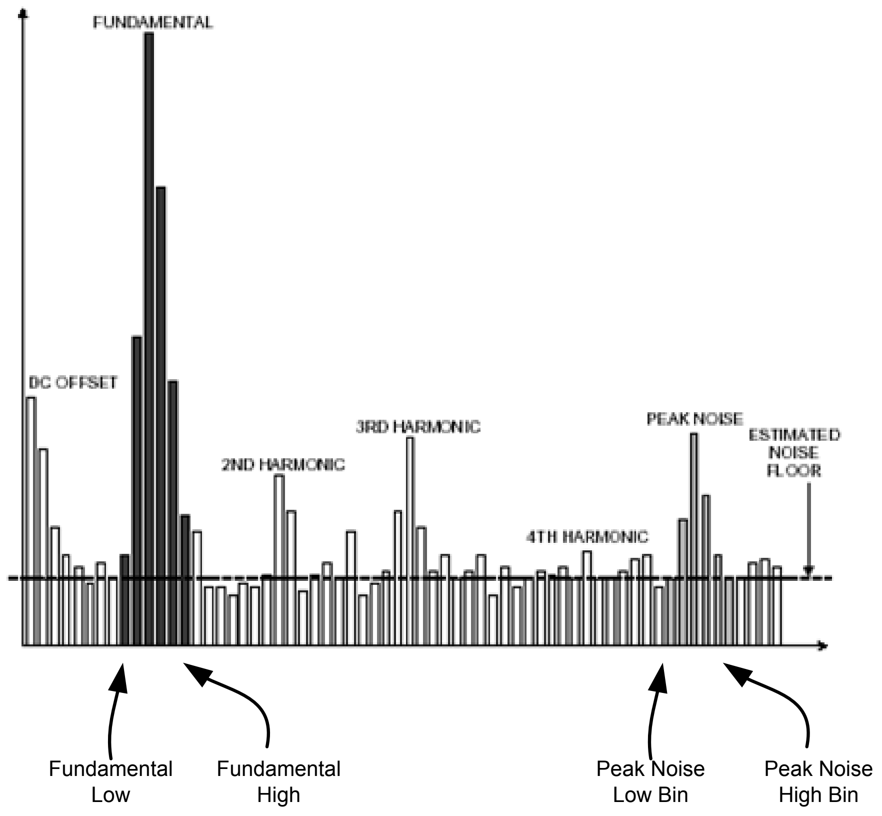

Start
Determine the Maximum Signal Frequency or Bin
Multiply frequency or bin by interger
Determine the signal magnitude for each multiple
Sum up multiple signal
SD = Fundamental / Sum(Harmonics)
END

FIGURE 26 SDR FLOWCHART

The next calculation is the signal-to-peak noise, SPN. [41]



Peak Noise = Sum Frequencies(Peak Low to Peak High)

SPN = Fundamental Signal / Peak Noise Signal

FIGURE 27 SIGNAL TO PEAK NOISE MAPPING

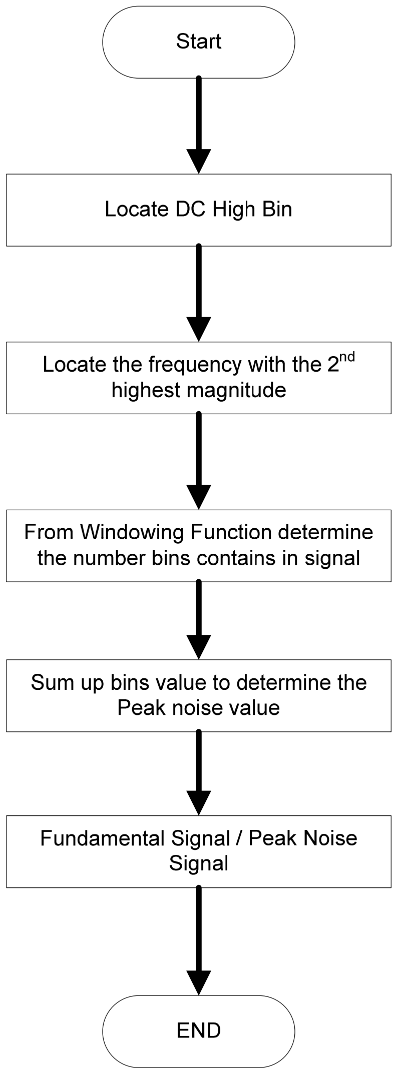

Start
Locate DC High Bin
Locate the frequency with the 2nd highest magnitude
From Windowing Function determine the number bins contains in signal
Sum up bins value to determine the Peak noise value
Fundamental Signal / Peak Noise Signal
END

FIGURE 28 SPN PSEUDO-CODE

The following is the pseudo-code for calculating the signal to noise plus distortion. The reciprocal of the SINAD is total harmonic distortion, THD. [42]

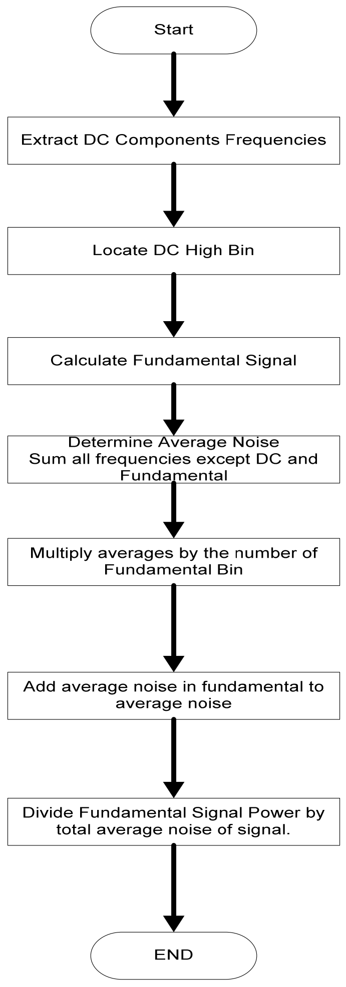

Start
Extract DC Components Frequencies
Locate DC High Bin
Calculate Fundamental Signal
Determine Average Noise Sum all frequencies except DC and Fundamental
Multiply averages by the number of Fundamental Bin
Add average noise in fundamental to average noise
Divide Fundamental Signal Power by total average noise of signal.
END

FIGURE 29 PSEUDO-CODE FOR SINAD

CHAPTER 4

UML

INTRODUCTION

The software architecture was designed using Unifying Modeling Language 2.0. I chose this technique to architect the solution because its implementation is platform independent, simplification of the problem by separating the problem into three views, and ease in modification. [43] I modeled the problem into three distinct views for two different environments. The first environment is for the actual setting registers and reading and writing to the chip being characterized. The second environment is the bench. It includes interfacing to power supplies, digital multimeters, and silicon thermal. For the chip, the class model represents the internal object of the ADC and the microcontroller. These internal objects include registers and analog input channels to the chip. The microcontroller controls the serial communication between the chip and the PC. In this model, I describe the relationship between different objects, attributes, and their operations. In the state model, the temporal behaviors of the objects are described. The events and controls are the stimulus used to change or move an object from one state to the next. The second environment is the bench test environment. The class model represents the peripheral used in characterizing the ADC. The state model is the events/controls used in automation. The interaction model shows how users interact with an application, in this case the test engineers and technician.

4.1 General Description for ADC Family

The CS5530/31/32/33/34 are highly integrated ΔΣ Analog-to-Digital Converters (ADCs) that use charge-balance techniques to achieve 16-bit (CS5531/33) and 24-bit (CS5530/32/34) performance. The ADCs are designed for measuring low-level unipolar and bipolar signals in weigh scale, process control, scientific, and medical applications. The ADCs come as either one-channel (CS5530), two-channel (CS5531/32), or four-channel (CS5533/34) devices. The design includes a very low noise chopper-stabilized programmable gain instrumentation amplifier (PGIA) with selectable gains of 1x, 2x, 4x, 8x, 16x, 32x, and 64x. The ADCs have a fourth order ΔΣ modulator followed by a digital filter which provides twenty selectable output word rates of 6.25, 7.5, 12.5, 15, 25, 30, 50, 60, 100, 120, 200, 240, 400, 480, 800, 960, 1600, 1920, 3200, and 3840 samples per second with a master clock rate (MCLK = 4.9152 MHz). The communication between the ADCs and micro-controller is a three-wire serial interface which is SPI and Microwire compatible with a Schmitt Trigger input on the serial clock. Figure 30 is the physical layout of CS5530 ADC. It is a one channel device with only a gain of 64X.

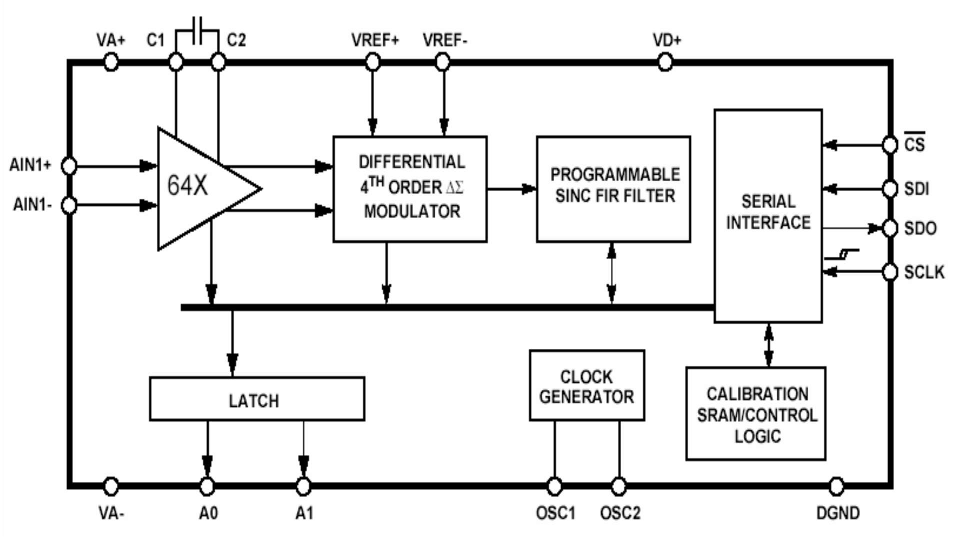
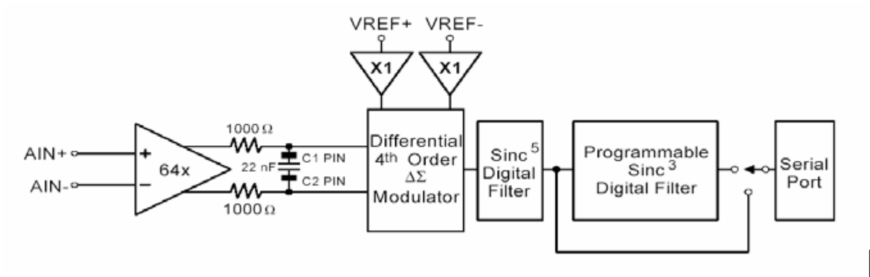


FIGURE 30 CS5530 ADC INTERNAL

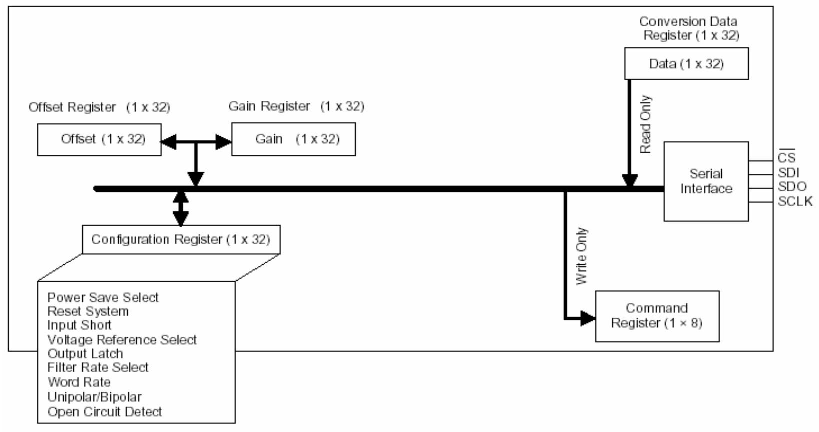
Figure 31 is the front end configuration which that includes a chopper-stabilizer instrumentation amplifier. [44]



[45]

FIGURE 31 FRONT END CONFIGURATION

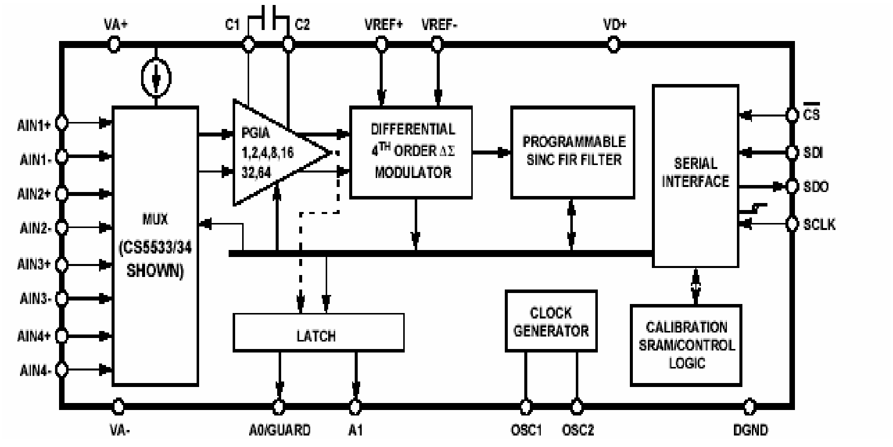
Figure 32 shows the block diagram of the on-chip controller's internal registers. The controller includes a number of user-accessible registers. The registers hold offset and gain calibration results, chip operating mode configuration, hold conversion instructions, and store conversion data words. There are two 32 bits registers that holds the offset and gain calibration. These registers are read/write, which allows calibration data to be off-loaded into an external EEPROM and allows the user ability to manipulate the register contents. This converter has a 32-bit configuration register which is used for setting options like power down modes, resetting the converter, shorting the analog input, enabling logic outputs, and so on. The CS5530 has a 64x gain not a programmable gain like the 31/32/33/34.



[46]

FIGURE 32 CS5530 REGISTERS

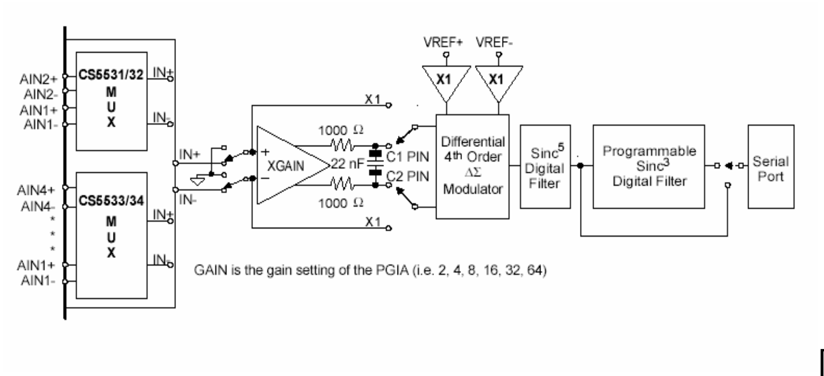
The following general descriptions are for the CS5531/32/33/34 ADCs. Figure 33 illustrates the ADC layout for this family of chips. Like the CS5530 these ADCs include a very low noise chipper-stabilized instrumentation amplifier. They have a programmable gain amplifier (PGIA) with selectable gains of 1x, 2x, 4x, 8x, 16x, 32x, 64x, (not in CS5530).



[47]

FIGURE 33 CS5531/32/33/34 ADC INTERNAL

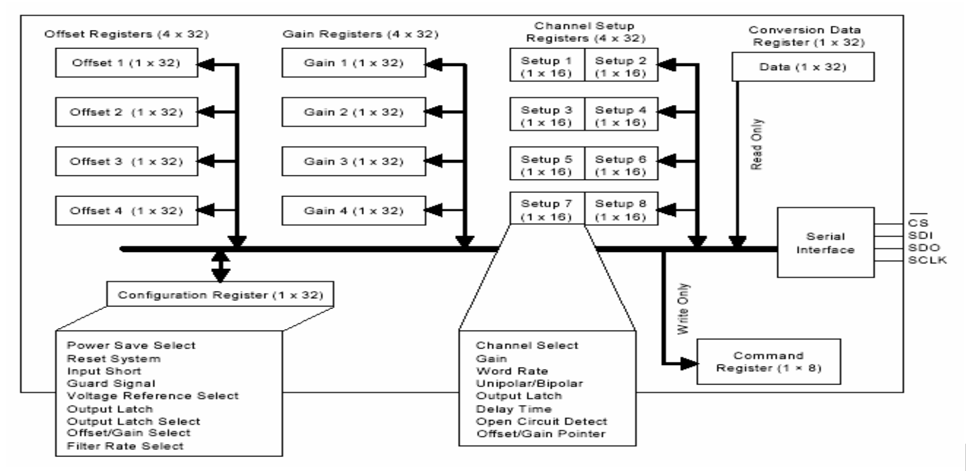
Figure 34 illustrates the block diagram of the CS5531/32/33/34. The front end consists of a multiplexer, a unity gain coarse/fine charge input buffer, and a programmable gain chopper-stabilized instrumentation amplifier. The unity gain buffer is started with any conversion that has a gain of one. The PGIA is activated with any conversion with a gain of greater then one.



[48]

FIGURE 34 CS5531-34 FRONT END

Figure 35 is a block diagram of the on chip controller registers. As with the CS5530, each converter has 32-bit registers to function as offset and gain calibration registers. Converters with two channels have two offset and two gain calibration registers and converters with four channels have four offset and four gain calibration registers that holds the calibration results. These registers are read/write. Also, there is a 32-bit configuration register that is used for setting converter options. There is a 32-bit conversion register that holds the converter data. It is read only register. There is an 8-bit command register that is write-only. There are a maximum of four registers called the Channel Setup Registers. They contain preloaded conversion instructions. Each channel setup register is 32 bits in length and holds two 16 bit conversion instructions. The number of channel setup is dependent on the number of input channels. For two channels device there are two channel setup register and for four channels, four channel setup register. CS5530 does not contain a channel setup register. The channel setup register can be initialized during power up by the controller. The converter can be instructed to perform single/multiple conversions or calibrations using the mode defined in the channel setup register. The channel setup registers can set the following modes of the chip: channel select, gain, word rate, unipolar/bipolar, output latch, delay time, open circuit detect, offset/gain pointer.



[49]

FIGURE 35 CS5531/32/33/34 REGISTER DIAGRAM

There are two conversion modes that this family of ADC can be set in. In single conversion mode an 8-bit command word is written to the serial port through the SDI input line. Within the command, there are three bits used as a pointer to point to the 16-bit command in the Channel Setup Register which is to be executed. The 16 bit setups can be programmed to do conversion on any input channel and more then one 16 bit setup can be used on an input channel. This allows the user to convert the same signal with different word rate, different gain range, or any of the channel setup options. The user also can setup different conversion characteristic on different channels. In continuous conversion mode, the ADC can continuously convert referencing only one 16 bit Channel Setup Register. In this mode the converted data is loaded into a shift register. When conversion is complete, the converter sets a flag on the SDO pin.

4.1.1 UML Class Model

Figure 36 is a diagram of the class model of the ADC. The super class is register. The register class has the behavior of writing and reading. This is inherited to the subclasses. As shown in the diagram the subclasses are offset, gain, channel setup, configuration, 8-bit command and conversion registers. They represent physical objects represented in the DUT. All the behavior is inherited from the super class to all registers except command and conversion registers. The command class inherits only the behavior of writing since it is a write-only register. The conversion register inherits only the behavior of reading since it is a read-only register.

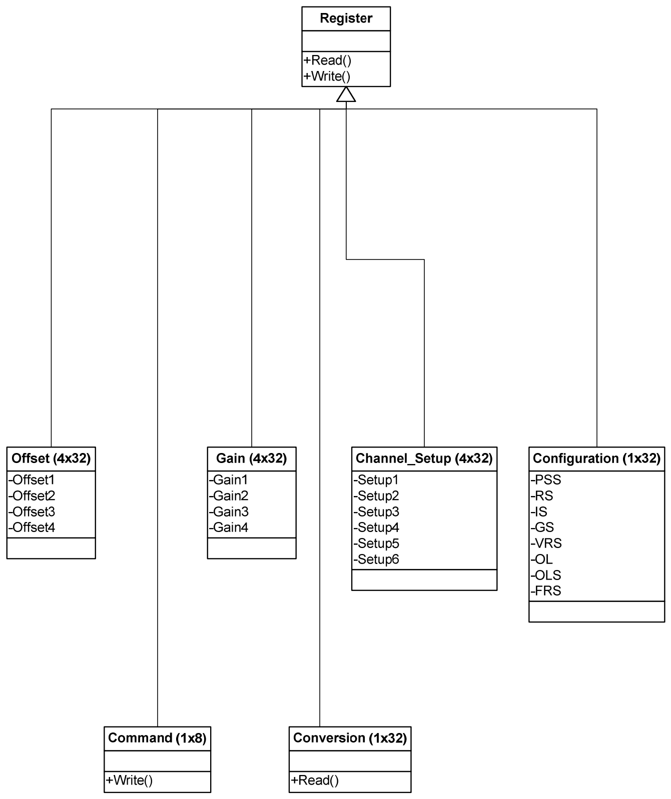


FIGURE 36 CLASS DIAGRAM OF DUT

4.1.2 UML State Model

I represented several key behaviors in the ADC and the microcontroller using state diagrams. The microcontroller is the link between the ADC and the computer using the universal serial bus. The first step to preparing the DUT for characterizing is to initialize the system. The initialization sequence comprises of initializing the serial port and a chip reset. Figure 37 shows the initialization sequence to place the serial port into command mode and reset the ADC. At least 15 SYNC1 command bytes, (0xFF hexadecimal,) are transmitted across the serial port. Then a SYNC0 command, (0xFE hexadecimal), is transmitted. [50] This establishes synchronization between the serial port clock on the microcontroller and the master clock of the device. The final step is the device reset. Figure 38 illustrates the steps to reset the ADC. The CS5530/31/32/33/34 serial interface is composed of four lines Chip Select, (CS), Serial Data In, (SDI), Serial Data Out, (SDO), Serial Clock, (SCLK). CS is used when there are several ADC connected together. The microcontroller toggle the CS line of the ADC that instructions are addressed too. Figure 39 is a diagram showing the read, write and data conversion cycle. When the CS pin get tied low the serial interface function using three wires. SDI line is used to transfer commands to the converter. SDO line is used to transfer data from the converter to the microcontroller. The serial clock is used in timing the shift of words to and from the ADC's through the serial port. Figure 40 -43 are state models of the read and write cycles. To validate the serial communication was properly working; I connected the chip to a logic analyzer through the header pins. I compared the timing diagram on the scope to that of figure 39.

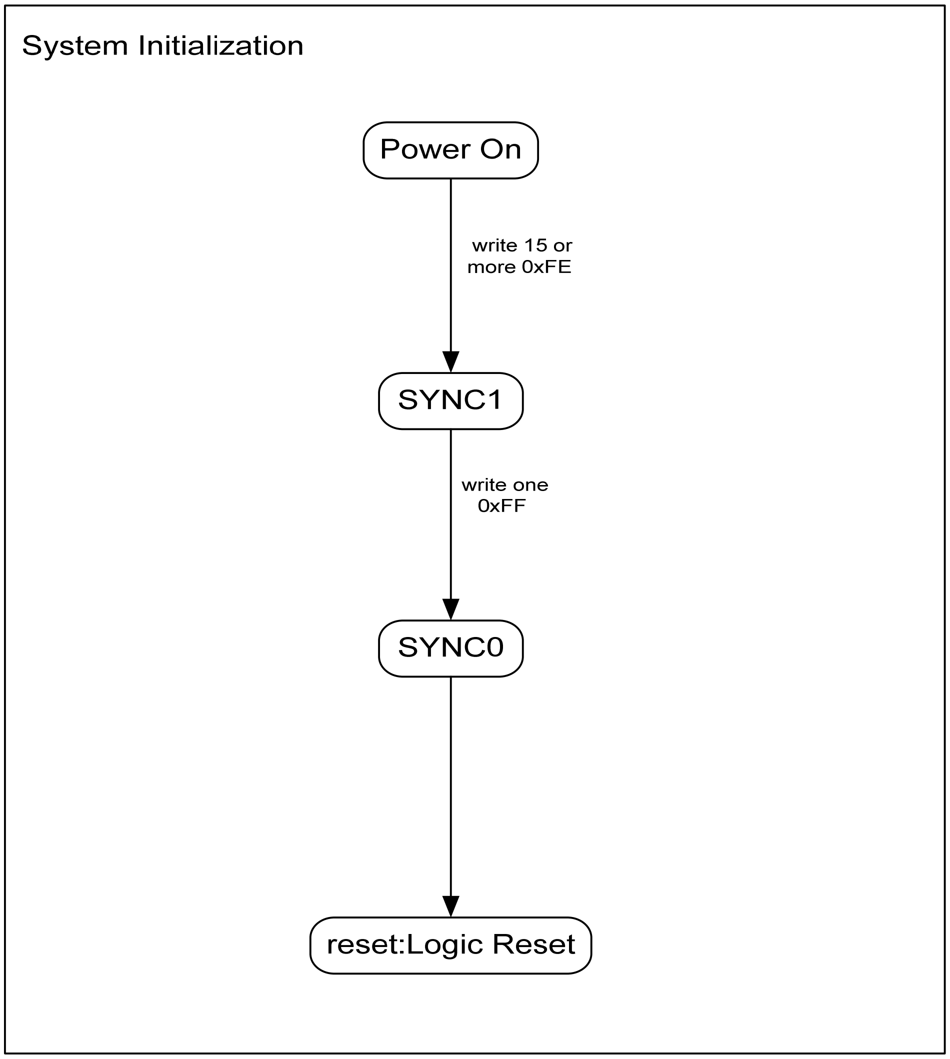


FIGURE 37 SYSTEM INITIALIZATION

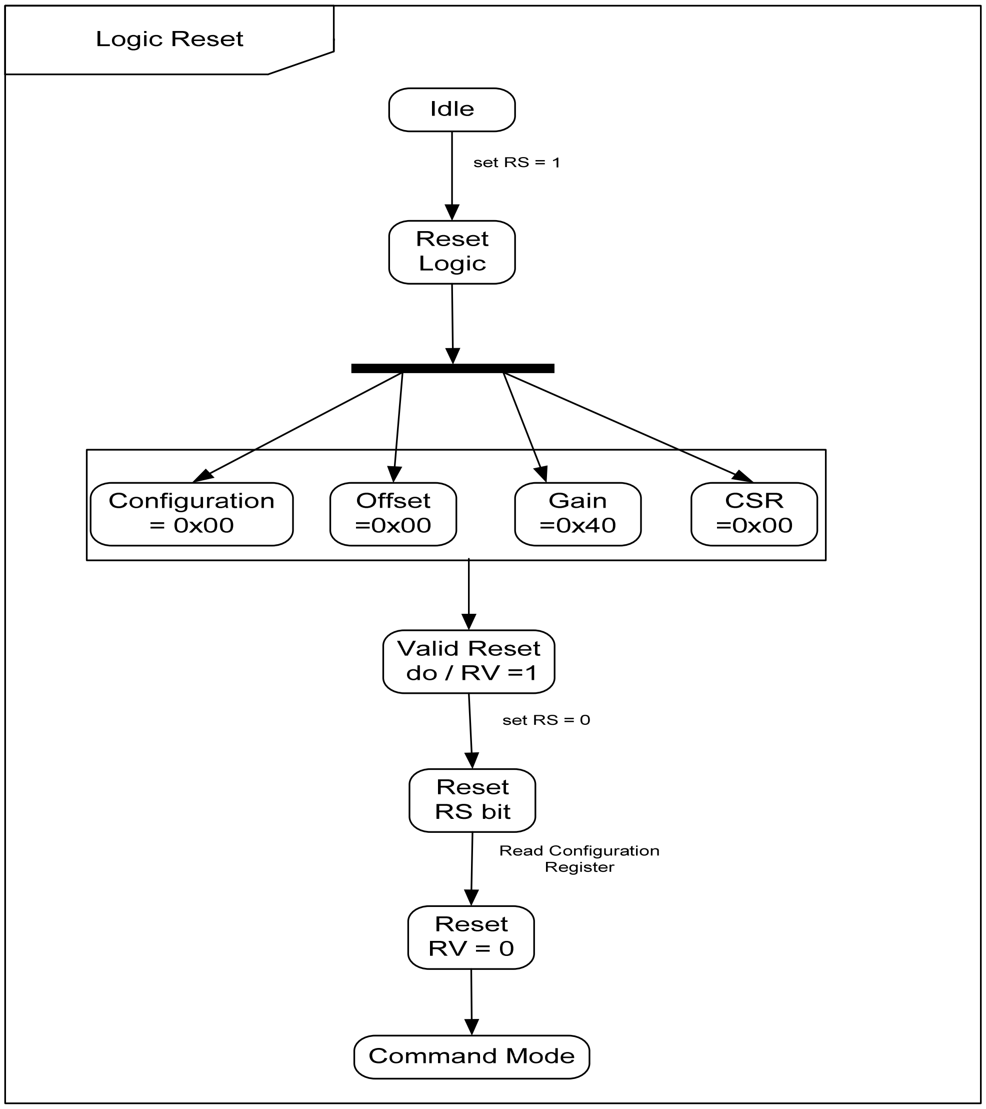
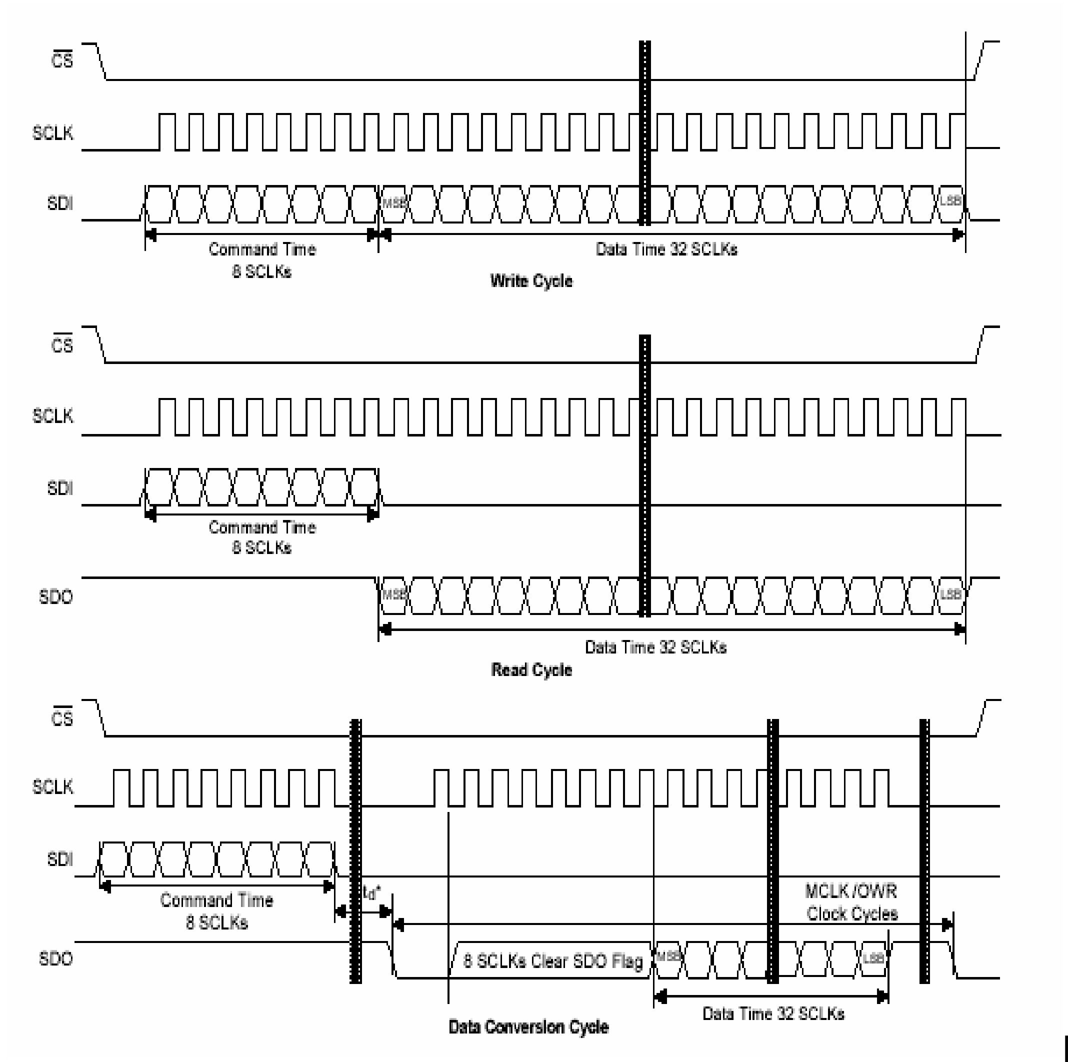


FIGURE 38 ADC RESET STATE MODEL



[51]

FIGURE 39 READ, WRITE, AND DATA CONVERSION TIMING DIAGRAMS

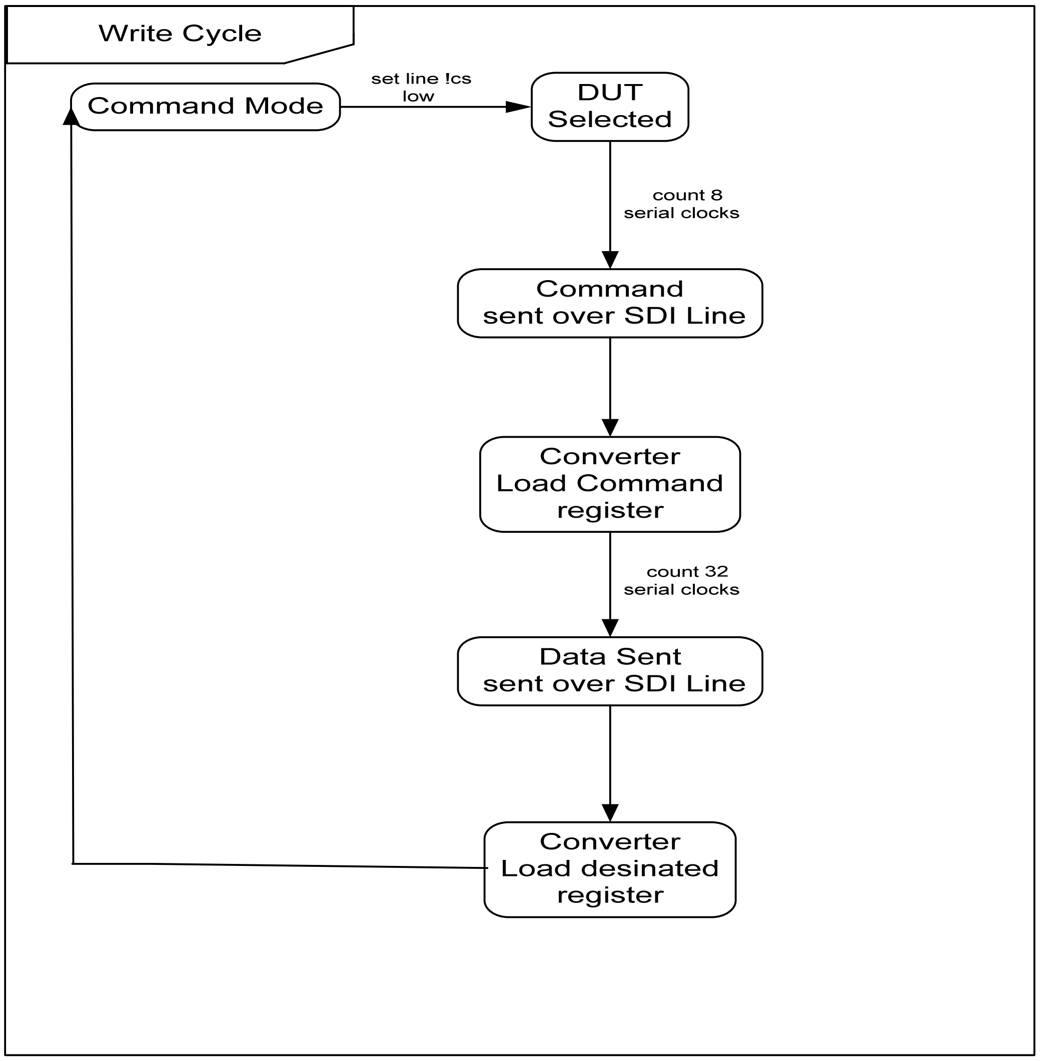

Write Cycle
Command Mode
set line !cs low
DUT Selected
count 8 serial clocks
Command sent over SDI Line
Converter Load Command register
count 32 serial clocks
Data Sent sent over SDI Line
Converter Load desinated register

FIGURE 40 WRITE CYCLE

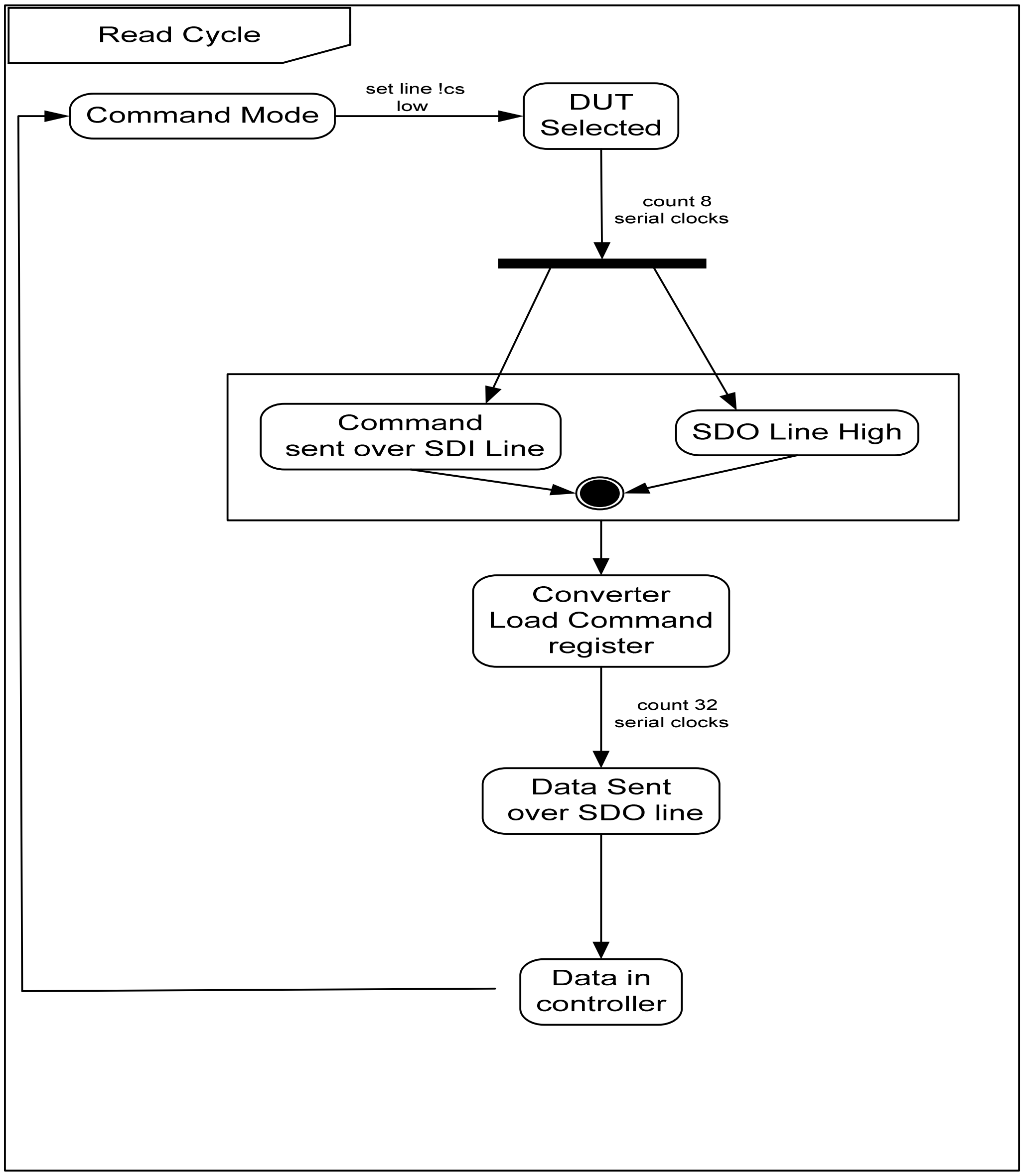


FIGURE 41 READ CYCLE STATE MODEL

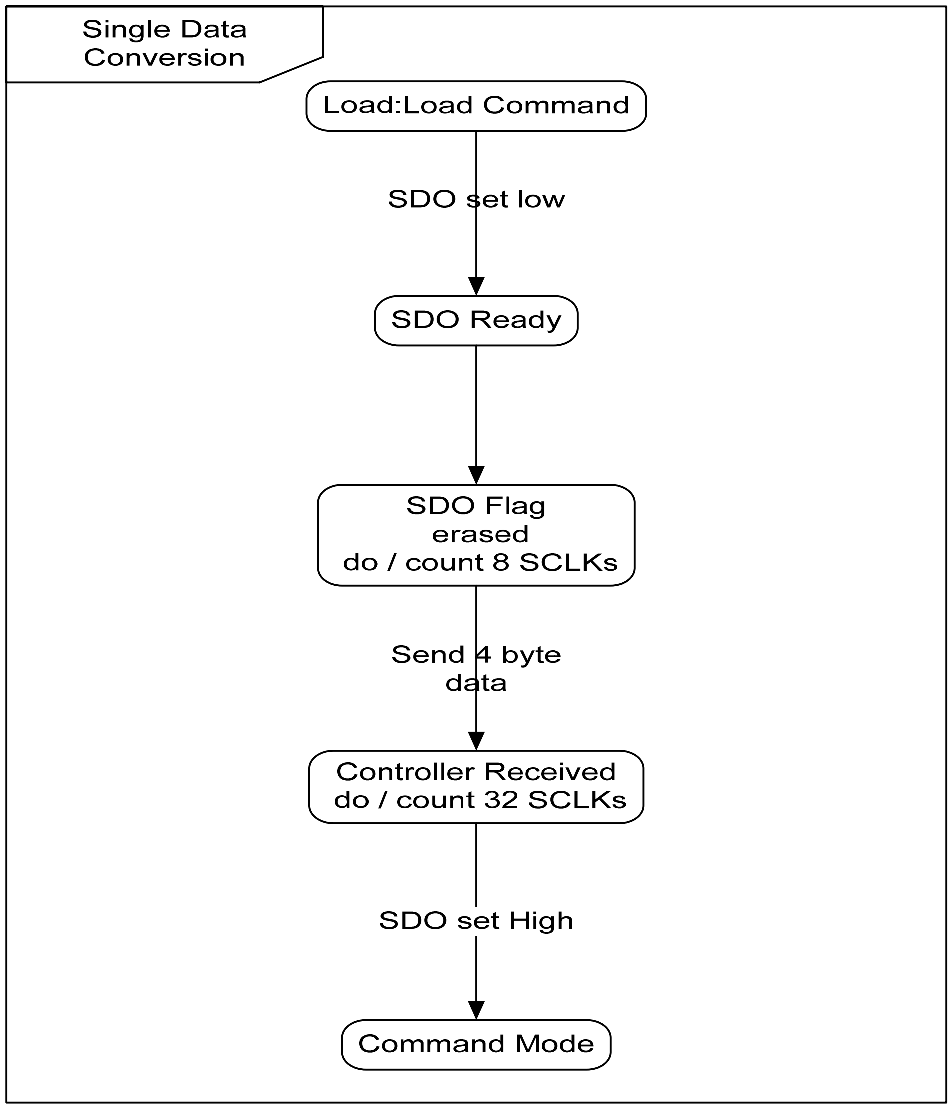


FIGURE 42 SINGLE DATA CONVERSION

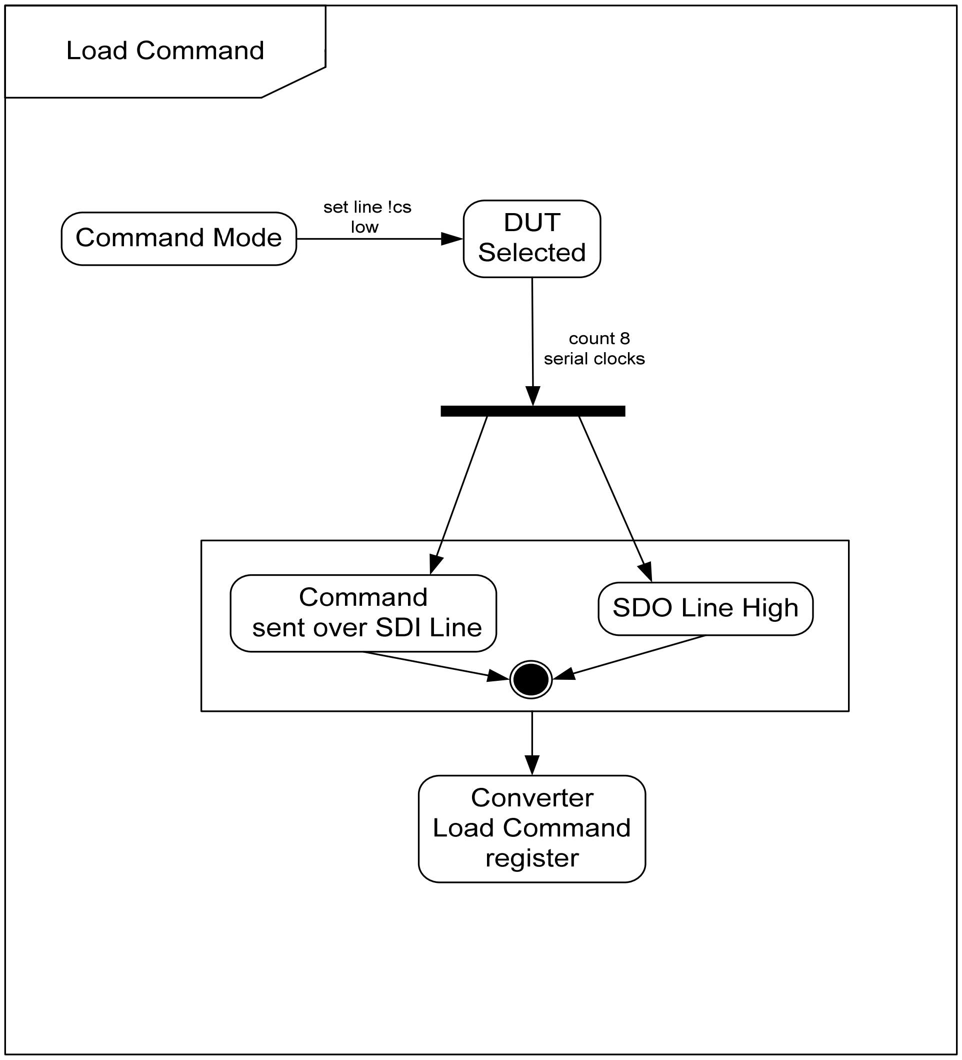
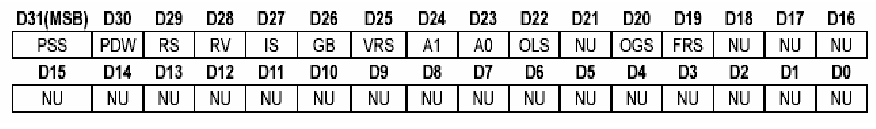


FIGURE 43 LOAD COMMAND SUB-STATE OF DATA CONVERSION

The write-cycle timing shows that the first 8 clocks cycles are used for shifting the command into the ADC's command register. The command is a byte in size a two digit hexadecimal number like 0xC0. The next 32 bits is the data. It takes 32 clocks cycle to shift in 32 bits of data, (one cycle for each bit). For example to write to the configuration register the command would be 0x03 and then 4 bytes of data would follow. Figure 44 shows the bit structure of the configuration register. The Acrobat file referenced in the bibliography contains the definitions for the acronyms.



D31(MSB)	D30	D29	D28	D27	D26	D25	D24	D23	D22	D21	D20	D19	D18	D17	D16
PSS	PDW	RS	RV	IS	GB	VRS	A1	A0	OLS	NU	OGS	FRS	NU	NU	NU
D15	**D14**	**D13**	**D12**	**D11**	**D10**	**D9**	**D8**	**D7**	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
NU	NU	NU	NU	NU	NU	NU	NU	NU	NU	NU	NU	NU	NU	NU	NU

[52]

FIGURE 44 CONFIGURATION REGISTER PIN OUT

The read cycle uses both the SDI and SDO lines. The command is shifted into the command register using eight clock cycles along the SDI line. The command is executed and then the data is shifted out using 32 clocks cycle through the SDO lines. The data conversion cycle is similar to read cycle except on the SDO line there is eight clock cycle used to clear the transmit buffer. Then the data is sent to the host or the computer bye the micro-controller. The data is shifted between the converter and the microcontroller in byte size. The microcontroller and the converter handshaking is done through the setting/resetting the SDO line. I will explain this in more detail later. Figure 45 and 46 illustrates the state model for the read and write register.

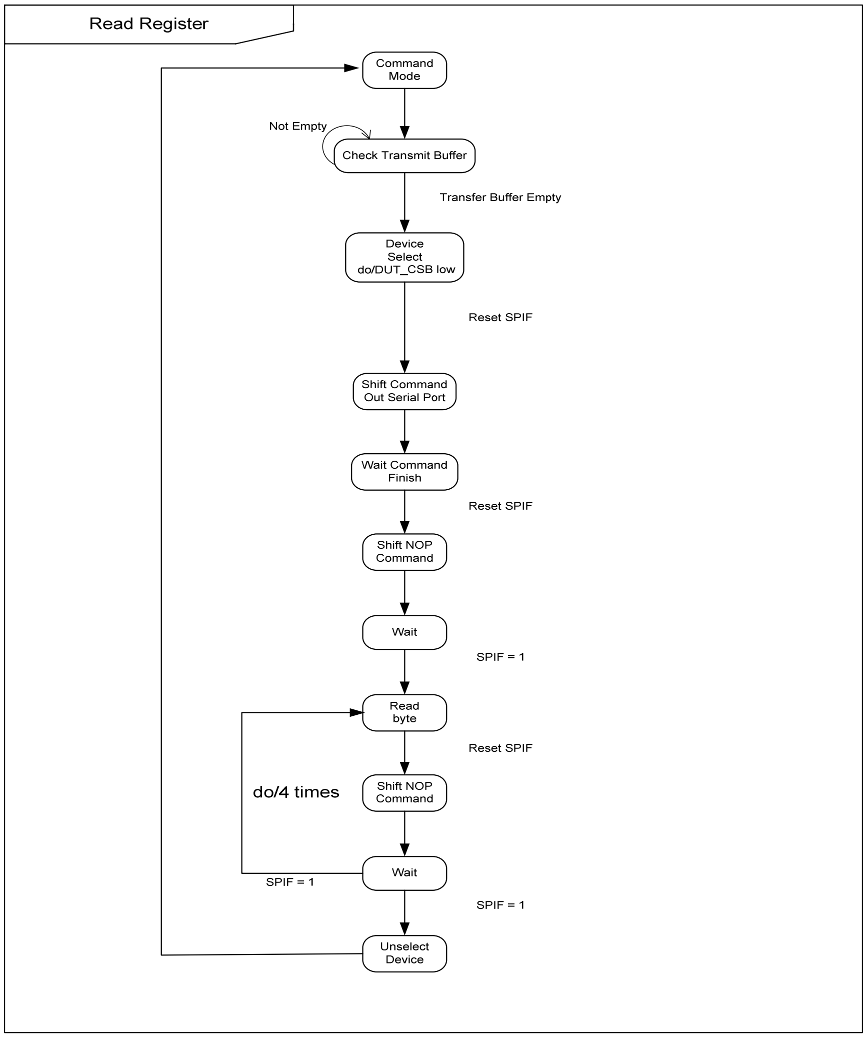


FIGURE 45 READ REGISTER STATE MODEL

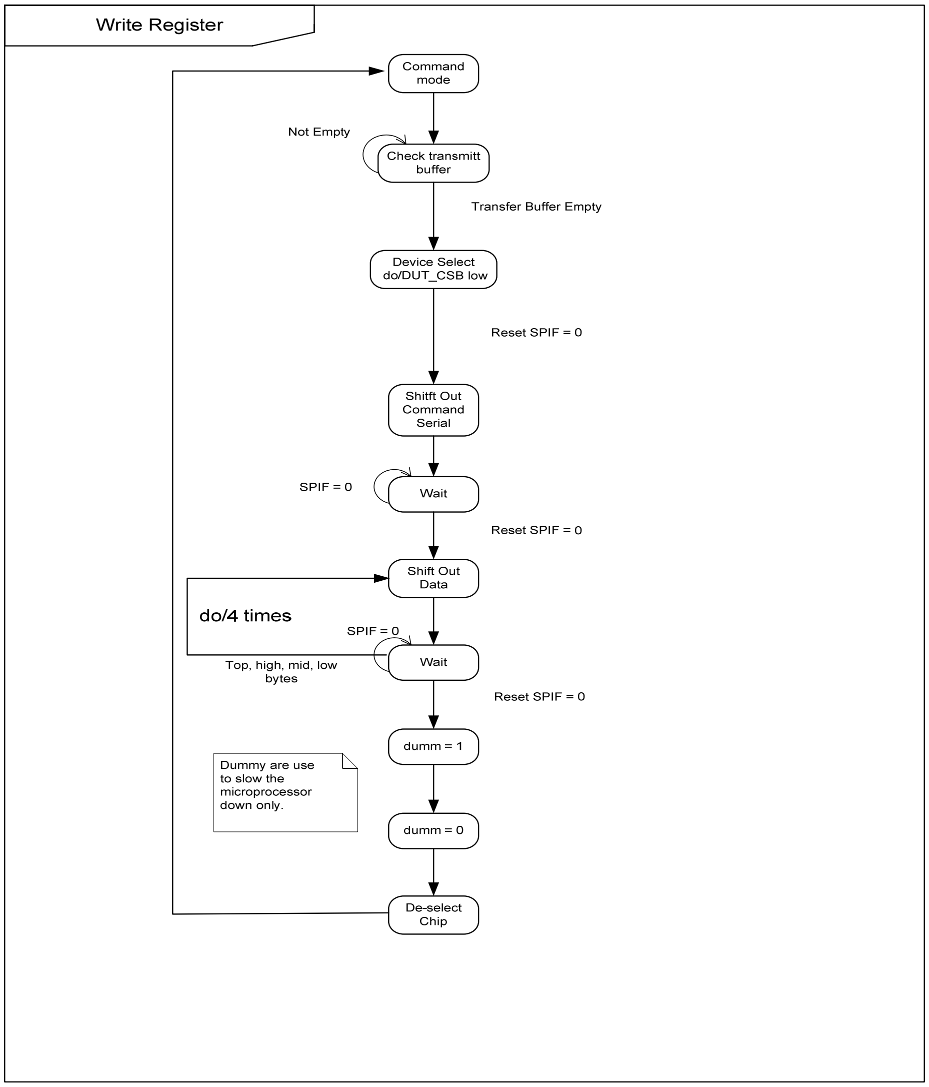


FIGURE 46 WRITE REGISTER STATE MODEL

Calibration is used to calculate the zero and gain slope of the ADC transfer function. There are two types system and self calibration. Each input channel has a corresponding offset and gain register to store calibration result. The registers are 32 bit long. The offset holes the zero value of the ADC conversion. The least significant bit (LSB) of 24 bit ADC is 1.835007966 x 2^{-24} instead of 1 x 2^{-24}. This is just an artifact of the chip design. The CS5531/32/33/34 has both self offset and self gain calibration. The CS5530 cannot self calibrate. When the chip self calibrate, it internal shorts the input channel to its internal ground. Figure 47 illustrates the steps to self calibrate. A bit is set to determine whether to read the channel or use the channel pointer from the channel setup register. Self calibration is valid for only 1x amplification.

For system calibrations, the user provides the ADC signals which represent ground and full scale. A ground, (zero input), is used to determine the offset value. Full scale voltage like five volts is used to determine the slope of the gain. For both calibrations the word rate should not exceed 120 samples per second to reduce the peak to peak noise. Figure 48 illustrates the steps to system calibrate.

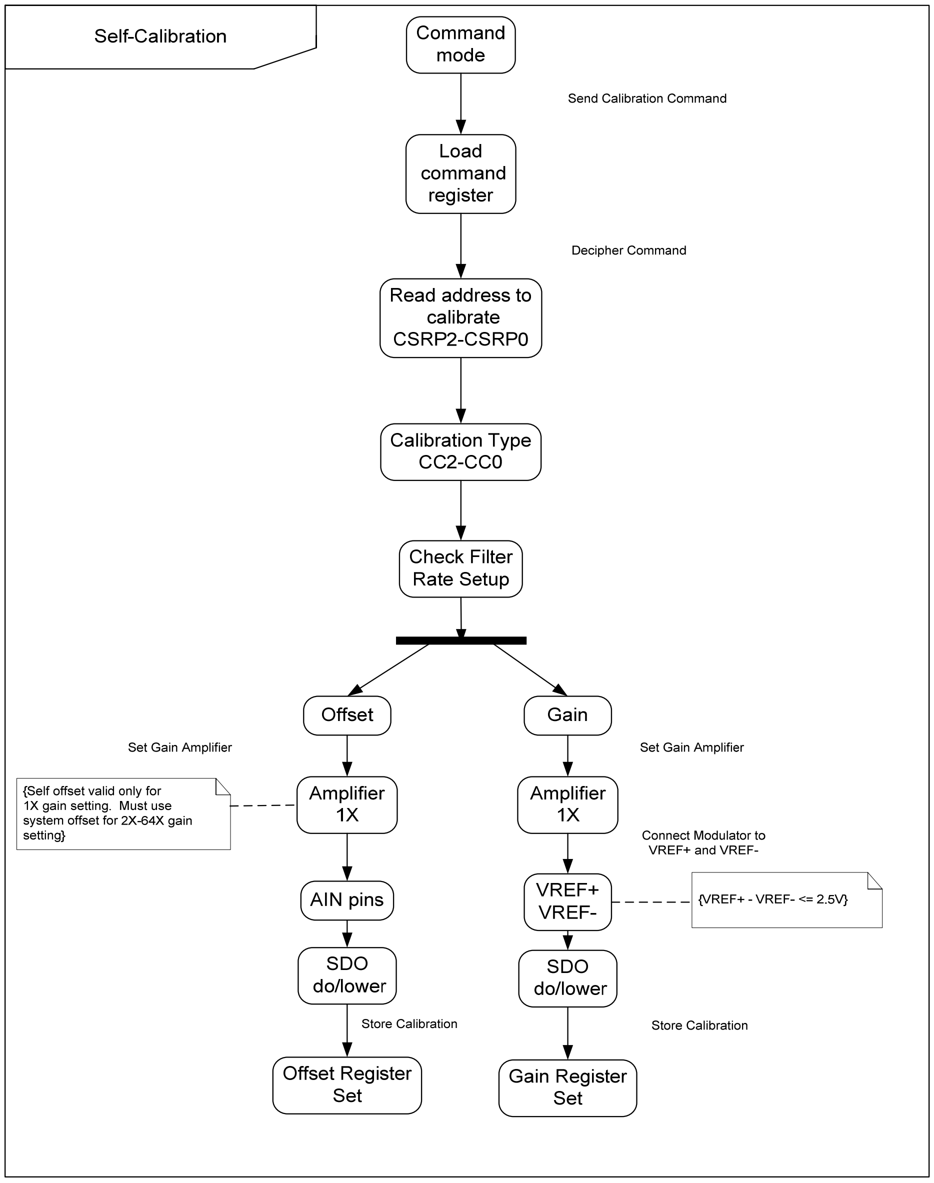


FIGURE 47 SELF CALIBRATION STATE MODEL CS5531-5534

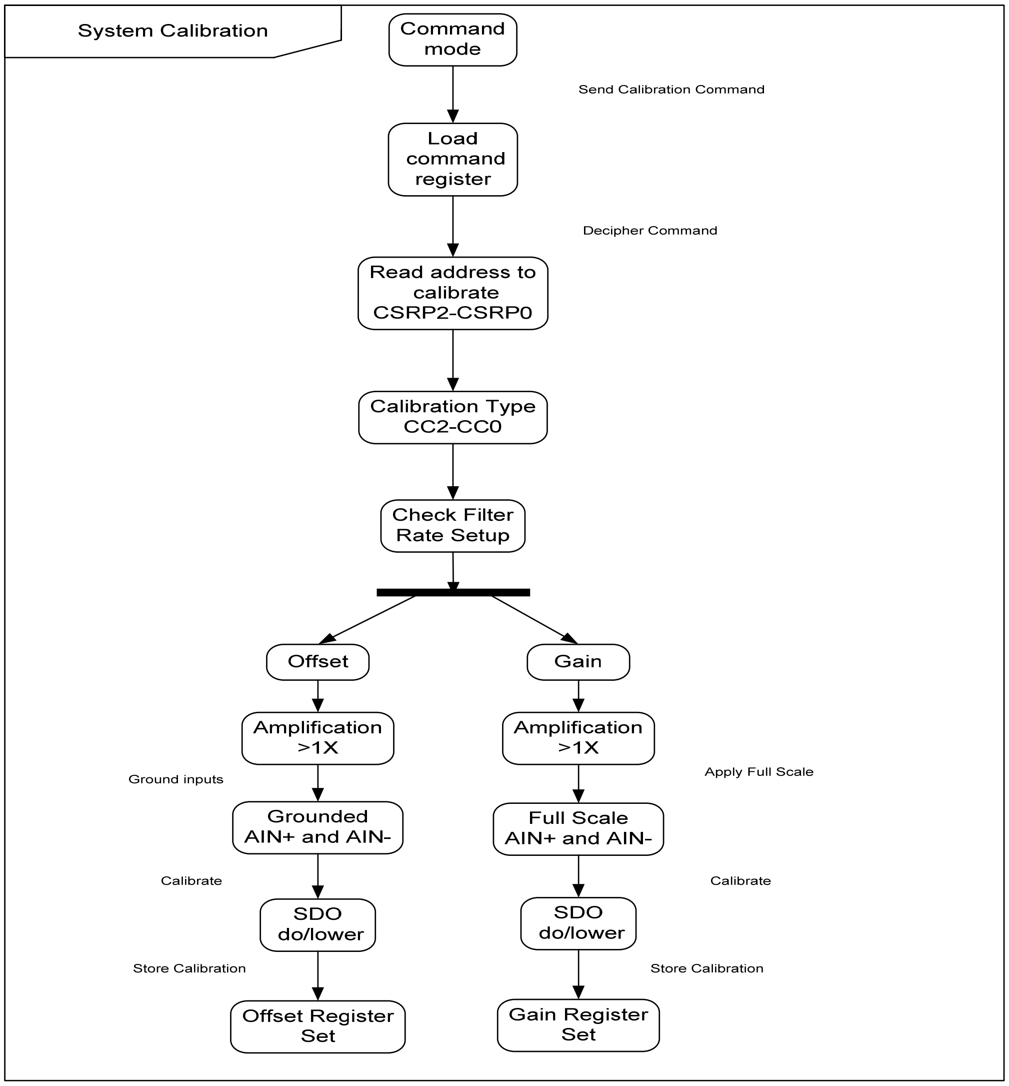
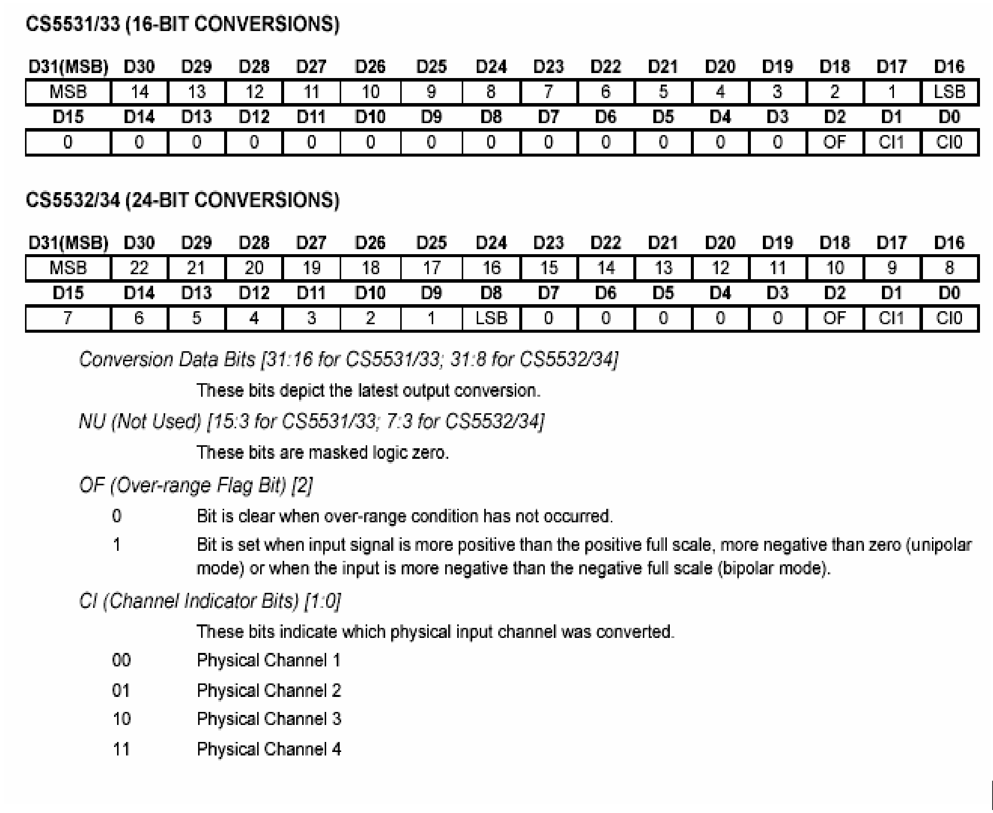


FIGURE 48 SYSTEM CALIBRATION STATE MODEL FOR CS553X

During conversion the binary word representing voltage across the input channel is stored in the chip’s conversion register. The conversion register is 32 bit in size. The actual converted word is either 16,(CS5531/33), or 24, (CS5530/32/34), bit long. During a conversion read, the ADC transmits the value stored in the conversion register on the Serial Data Out line to the microcontroller. The output is most significant bit, (MSB), first. Figure 49 shows the bit layout for the conversion register for the CS5531/32/33/34 chips with acronyms definitions. Bits D0 and D1 indicate the physical input channel converted. Figure 50 shows the bit layout for the CS5530 chip with its acronyms. There are no channel indicator bits because there is only one input channel for CS5530.



CS5531/33 (16-BIT CONVERSIONS)

D31(MSB)	D30	D29	D28	D27	D26	D25	D24	D23	D22	D21	D20	D19	D18	D17	D16
MSB	14	13	12	11	10	9	8	7	6	5	4	3	2	1	LSB
D15	**D14**	**D13**	**D12**	**D11**	**D10**	**D9**	**D8**	**D7**	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
0	0	0	0	0	0	0	0	0	0	0	0	0	OF	CI1	CI0

CS5532/34 (24-BIT CONVERSIONS)

D31(MSB)	D30	D29	D28	D27	D26	D25	D24	D23	D22	D21	D20	D19	D18	D17	D16
MSB	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8
D15	**D14**	**D13**	**D12**	**D11**	**D10**	**D9**	**D8**	**D7**	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
7	6	5	4	3	2	1	LSB	0	0	0	0	0	OF	CI1	CI0

Conversion Data Bits [31:16 for CS5531/33; 31:8 for CS5532/34]

These bits depict the latest output conversion.

NU (Not Used) [15:3 for CS5531/33; 7:3 for CS5532/34]

These bits are masked logic zero.

OF (Over-range Flag Bit) [2]

0	Bit is clear when over-range condition has not occurred.
1	Bit is set when input signal is more positive than the positive full scale, more negative than zero (unipolar mode) or when the input is more negative than the negative full scale (bipolar mode).

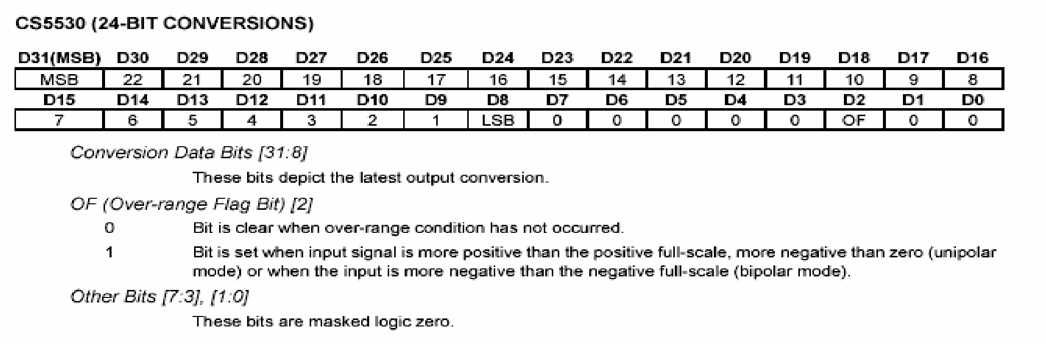
CI (Channel Indicator Bits) [1:0]

These bits indicate which physical input channel was converted.

00	Physical Channel 1
01	Physical Channel 2
10	Physical Channel 3
11	Physical Channel 4

[53]

FIGURE 49 CONVERSION REGISTER DATA OUTPUT DESCRIPTIONS



CS5530 (24-BIT CONVERSIONS)

D31(MSB)	D30	D29	D28	D27	D26	D25	D24	D23	D22	D21	D20	D19	D18	D17	D16
MSB	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8
D15	**D14**	**D13**	**D12**	**D11**	**D10**	**D9**	**D8**	**D7**	**D6**	**D5**	**D4**	**D3**	**D2**	**D1**	**D0**
7	6	5	4	3	2	1	LSB	0	0	0	0	0	OF	0	0

Conversion Data Bits [31:8]

These bits depict the latest output conversion.

OF (Over-range Flag Bit) [2]

0	Bit is clear when over-range condition has not occurred.
1	Bit is set when input signal is more positive than the positive full-scale, more negative than zero (unipolar mode) or when the input is more negative than the negative full-scale (bipolar mode).

Other Bits [7:3], [1:0]

These bits are masked logic zero.

FIGURE 50 CS5530 CONVERSION DATA OUTPUT DESCRIPTIONS

There are two conversion modes: single and continuous conversion. In single conversion mode a single fully settled conversion is perform at the word rate and polarity specified in the configuration or channel setup register. When the command byte is transmitted to do a single conversion, the serial port enters data mode where it wait until the conversion is complete. Completion is single when the converter set the SDO flag to logic 0. Then there are forty serial clock cycles needed to read the conversion. Figure 51 is a state model of the single conversion. In continuous conversion mode, the convert again begin conversion at the word rate and polarity set in the configuration or channel setup register. After conversion is done, the converter lowers the SDO line. Again forty serial clock cycles are needed to read the data. To remain in continuous conversion mode, during the first 8 serial clocks 0x00 must be transmitted across the SDI line. The microcontroller shifts the information to the host computer based on the rise and fall of the SDO line. It is not necessary to read all the converted data.

Missed read conversions are lost. To exit continuous conversion mode, during the first 8 serial clocks (clearing the SDO flag), a 0xFF must be transmitted across the SDI line to the converter. Figure 52 illustrates the continuous conversion process.

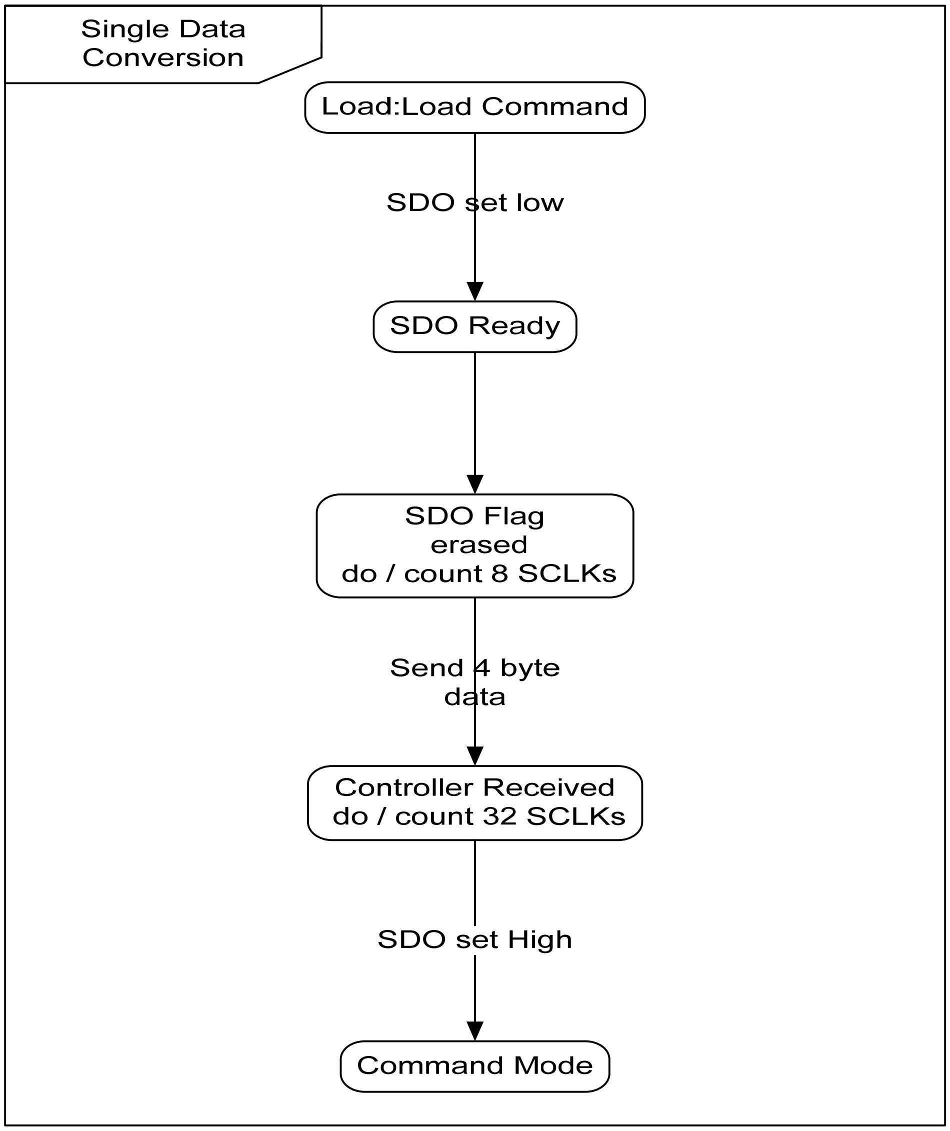


FIGURE 51 SINGLE DATA CONVERSION STATE MODEL

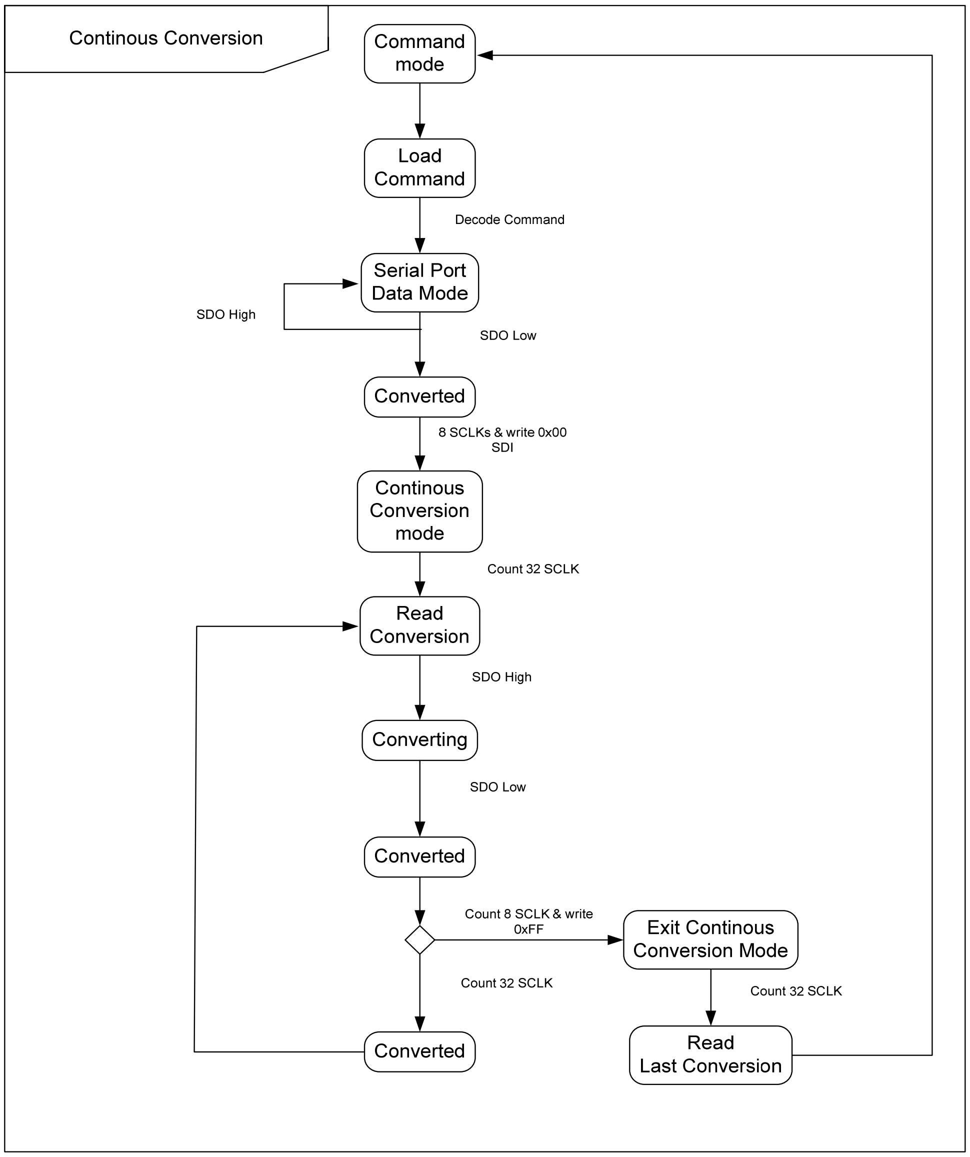
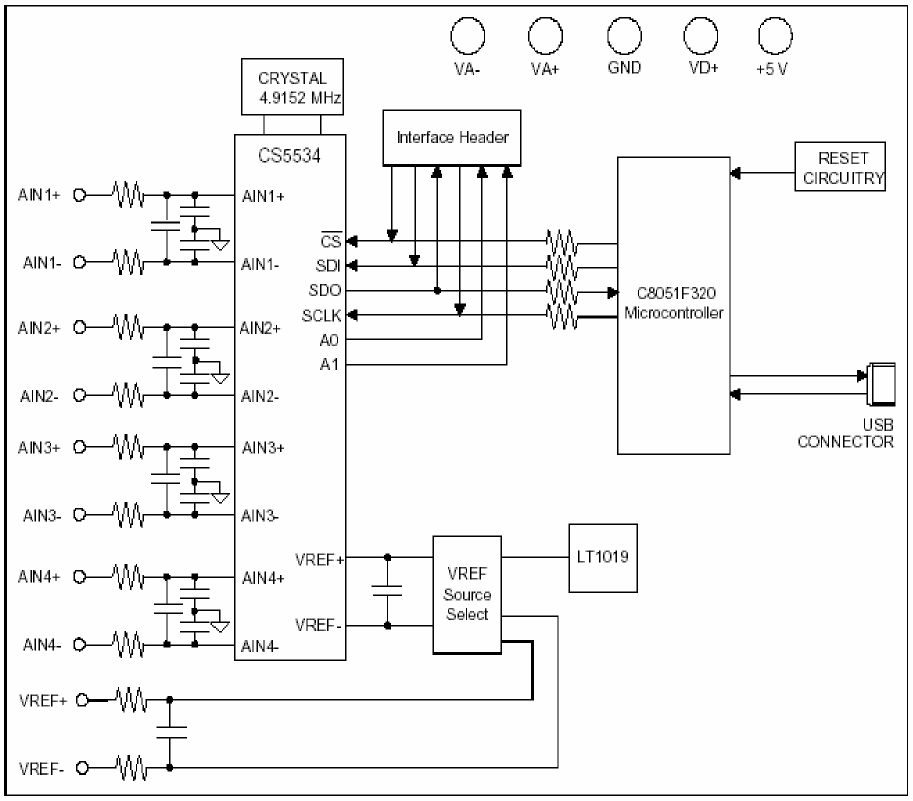


FIGURE 52 CONTINUOUS CONVERSION STATE MODEL

4.2 Microcontroller



[54]

FIGURE 53 BOARD LAYOUT

Figure 53 is a layout of the test board that is sold to customers for evaluation of the product. The square entitled C8051F320 is the microcontroller. There is a bidirectional interface to the right that is the universal serial bus connector. The ADC in this case, CS5534 is to the left of the controller. The interface protocol used by the microcontroller to communicate with the chip, is

SPI. SPI is composed of three wires (SDI, SDO, and SCLK). The SDI line is used to transmit data from the controller to the ADC. The SDO line is used to transmit data from the ADC to the controller. The CS line is for chip select. The microcontroller acts like an interpreter converting USB formatted commands from the PC to SPI format to the ADC and vice versa. For this family of ADC, a 4.9152 MHz crystal is tied to the oscillator pin of chip, providing the master clock. The conversion rates and the internal circuitry of the chip are based on this clock. The SCLK is used to synchronize the SPI with the microcontroller. It is based on C8051 24 MHz clocked divided by 2. The Interface Header composed of five pairs of male pins, and I connected the logic analyzer too for examining the timing diagram across the SPI interface.

The controller communicates to the personal computer through the universal serial bus, (USB). The universal serial bus is replacing the RS232 Ports in desktops and laptops. There are several benefits in using USB: [55]

Low Cost
Low power consumption
Plug & Play
Easy to Use
Fast
Reliable

Low cost is a major reason for this transformation. It is inexpensive to add USB functionality to an existing device because the translator interface exists in the operating system. There is only one interface for many devices, and the USB port is hot pluggable. The USB is a reliable way to transfer information because it offers lossless data transfers. As a result, developers do not need to implement any type of error correction on the device PC side. The USB protocol and hardware handles this feature.

The data is transferred through endpoints between the host and the device. Endpoints transfer data unidirectional either in or out except for control endpoints which are bidirectional. Control endpoints are used during the enumeration or configuration process. A pipe is the logical connection or association between the endpoint and the host controller's software. There are four types of USB transfer modes: [56]

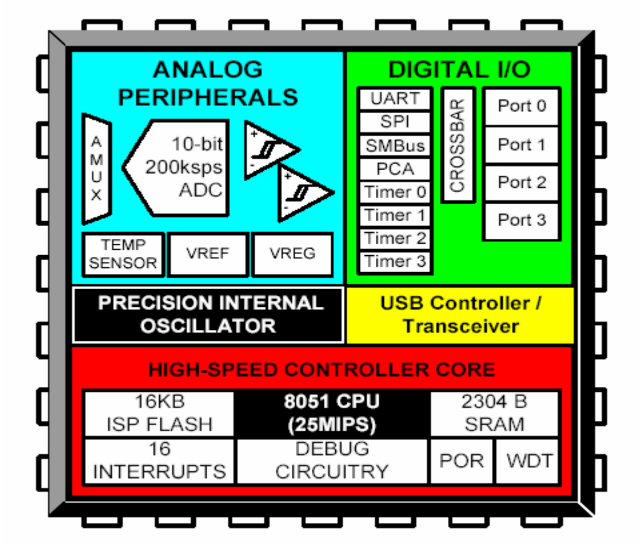
Control
Bulk
Interrupt
Isochronous

In my application the transfer mode used is Bulk. Bulk transfer has the fastest transfer rate. There is no guarantee of data rate or latency, which means the USB host will do its best to transfer the data as fast as possible. Applications such as this are for devices transferring large amounts of data (tens of megabytes to gigabytes). The USB host will allocate all bandwidth on the bus for this transfer. The throughput is dependent on the number of devices connected to the bus. Top speeds are: [57]

High Speed – 53.2 Mbytes/sec
Full Speed – 1.2 Mbytes/sec
Low Speed – Not Available

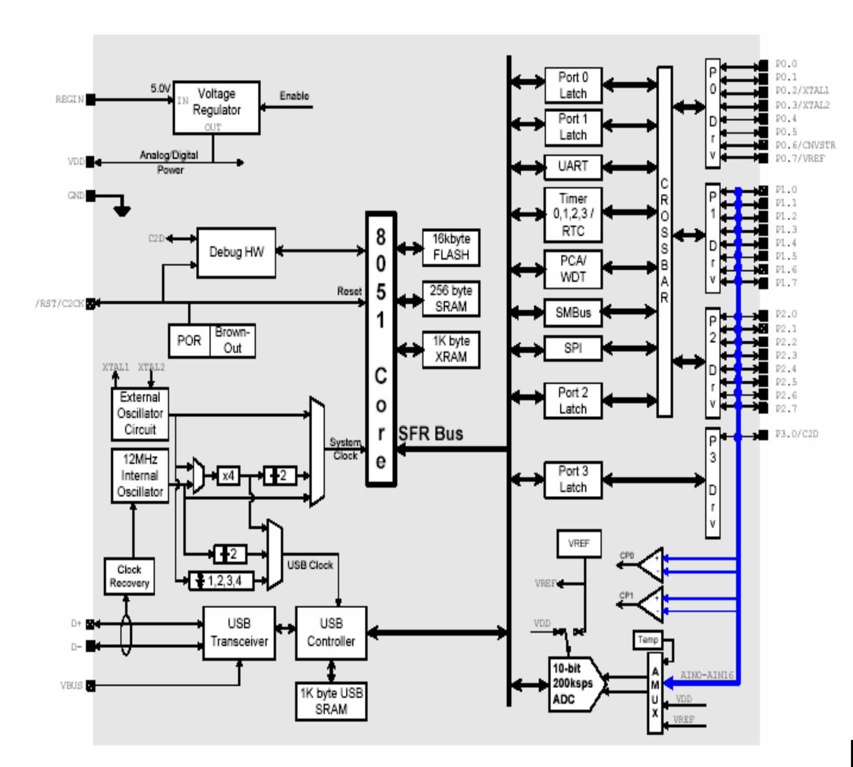
Common applications are printers, scanners, and disk drives (USB thumb drives).

The microcontroller used in this project was Silicon Lab's C8051F320/1. It is a programmable USB device that includes an on-chip USB function controller. The function controller is composed of a serial interface engine, a USB transceiver, and a 1 Kbyte endpoint space buffer that can hold up to four endpoints. It is USB 2.0 compliant and has its own integrated on-chip oscillator with an accuracy of 1.5% to support USB standards. The core is C8051. Figures 54 and 55 are diagrams of the C8051F320.



[58]

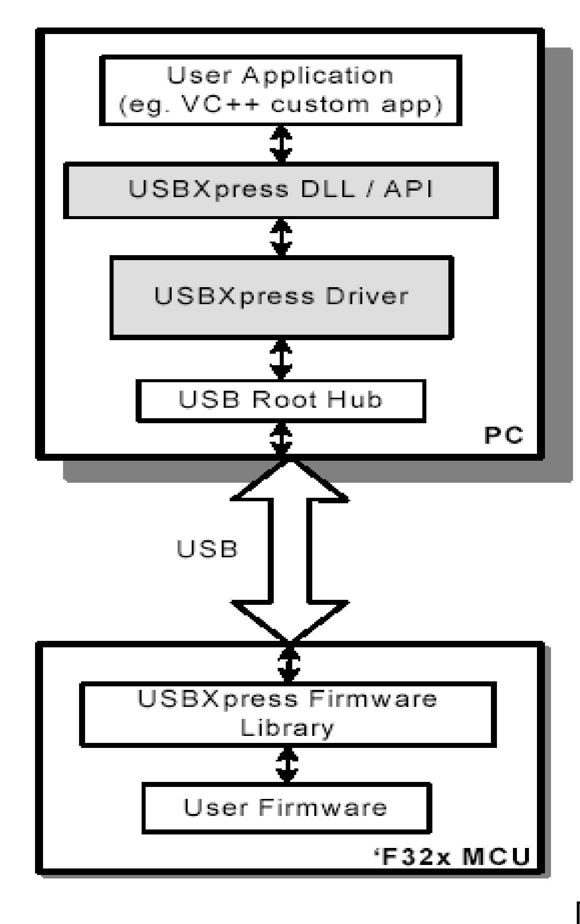
FIGURE 54 C8051F320 MICROCONTROLLER INTERNAL LAYOUT



[59]

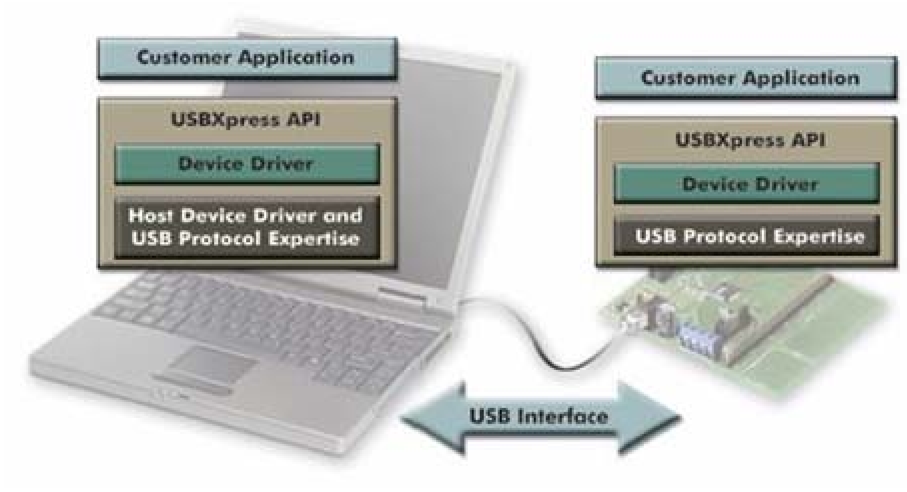
FIGURE 55 C8051F320 BLOCK DIAGRAM

Figure 55 shows 16 interrupts and digital input/output protocols for UART, SPI, SMBUS and PCA. There are 4 timers. For the microcontroller development I used USBXpress, which is the name of the microcontroller USB drivers. USBXpress is a package that includes the firmware and PC-side libraries. [60] The configuration of USB and the data transfer are completely handled by the high-level Application Program Interface (API). It is freely downloaded from the Silicon Laboratories website with freely distributable drivers and no royalties. The device drivers have support for Window 98SE, 2000, and XP. The compiler that comes with the free version of USBXpress has a file size limit that was too small for my application. I used a $3000.00, Keil C51 compiler and interfaced it through the Silicon Labs integrated development environment. I allocated one IN endpoint and Out endpoint on the C8051F320. Figure 56 illustrates the USBXpress data flow between the PC and microcontroller.



[61]

FIGURE 56 USBXPRESS DATA FLOW



[62]

FIGURE 57 EXPRESS API FOR PC AND DUT (DEVICE UNDER TEST)

A JTAG connects to the header pins associated to the microcontroller to comm port of the computer. The microcontroller code is loaded through this connection with the Silicon Lab's IDE. USB interrupt 16 is used by the software application on the PC to get the microcontroller's attention for writing or reading data from it. The micro code runs continuously, while(1), in a thread on the microcontroller. The program contains flags that jump to functions. Figure 58 is the state model of the infinite loop program within the microcontroller that I programmed. Let's say that a USB 16 interrupt occurred and the IDFL = 1, the microcontroller jumps to function Gui_version( ) and block writes that value to the controller's USB port that gets uploaded to the PC software. The flag is reset and function returns. The flags are:

IDFL – Identity Flag

RSFL – Reset Flag
RDFL – Read Flag
WRFL – Write Flag
SCFL – Single Conversion Flag
CCFL – Continuous Conversion Flag

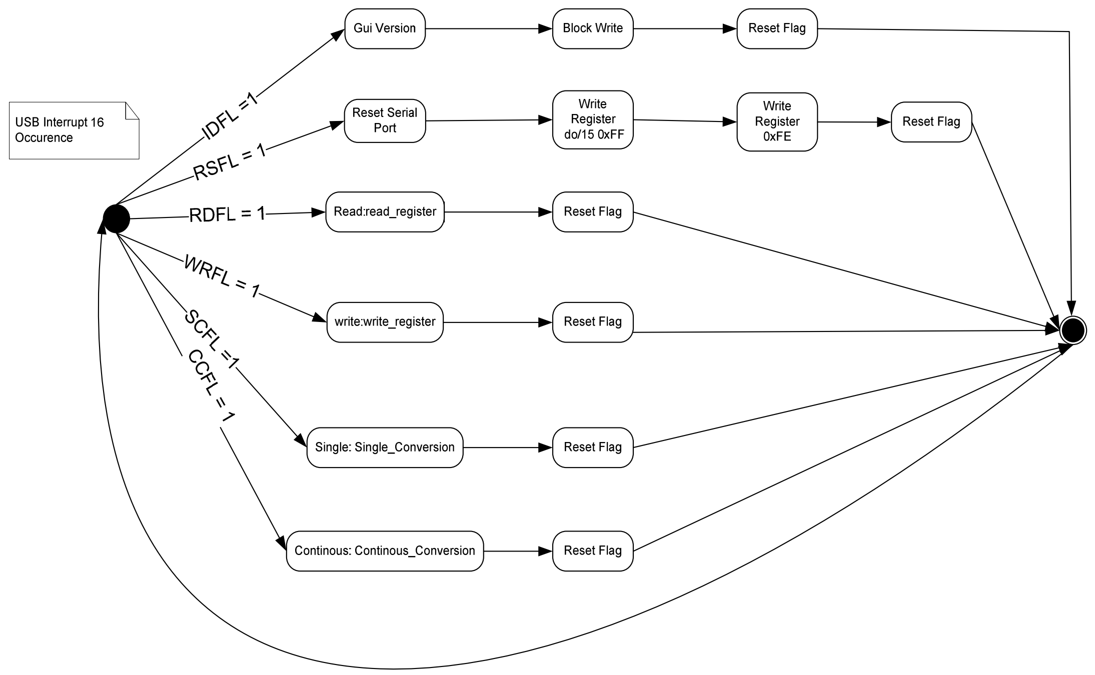


FIGURE 58 MICROCONTROLLER STATE MODEL

4.3 Bench Test Environment

During the characterization and validation of the chip, its supply voltage, temperature, and internal configurations are modified to specific conditions to see if the chip meets specification requirements. In bench testing there are several objects used: power supplies that supply the range of voltages to the device, “Silicon Thermals” that set the device temperature, and a digital multimeter to read output voltages and currents. Figure 59 is the class model of the bench tester and multiplicity. A power supply can only connect to one evaluation board. The chip requires several voltages settings at each modification. A “Silicon Thermal” can only be connected to one chip during a test. There can be several digital multimeter readings of voltages and currents during a test.

4.3.1 Class Model

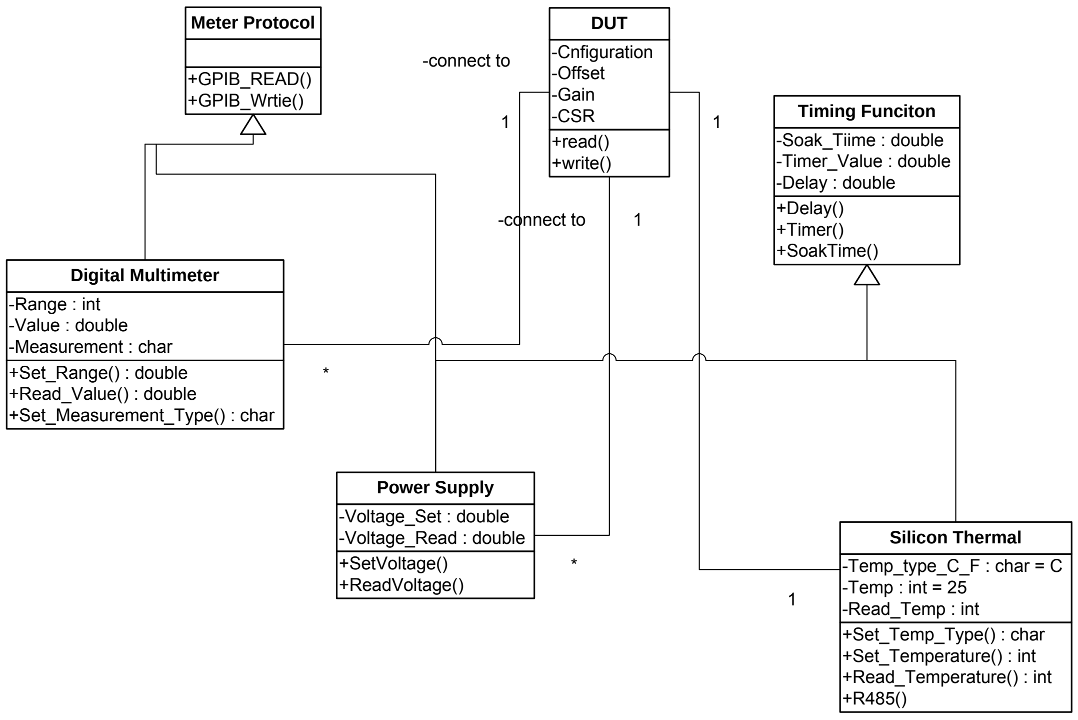


Figure 59 Bench Test Class Model

4.3.2 State Model

In the state model all peripherals are first warmed up for thirty minutes. This prevents the peripheral's settings from drifting. The "Silicon Thermal" is dialed to the desired temperature. There is a thermal couple placed between the metal head of the "Silicon Thermal" cooling and the DUT, (Device Under Test). The thermal couple is used to monitor the actual chip temperature. The silicon thermal remains in the ramp test state until it reaches the set temperature. Next, the power supplies are set to necessary voltage. Each power supply has three voltage ranges: 6, 25, and -25 volt setting with current limits set to maximum. The test voltages are loaded into power supplies. The voltage setting is read back from the power supply and if the voltage setting is equal to the index value then the process moves to the DUT state. The DUT state has been covered above. The DUT's calibration, offset, and gain register are loaded. Every value loaded into the DUT registers are read back for validation in a function called Decode(). If the values have been loaded correctly, the DUT software application is run and the following output values are calculated: SNR, S/D, SNAID, S/P, maximum, minimum, mean, standard deviation, and variance. The digital multimeter is read and all the output parameters are stored into a file. Figure 61 is the state model for setting up the test and storing device characteristics.

For automation, the tester through the bench test panel in the software stores setup values in “Struct” data structure. There are structures for each of the classes in the class model. I will discuss this in more detail in the implementation section of this project.

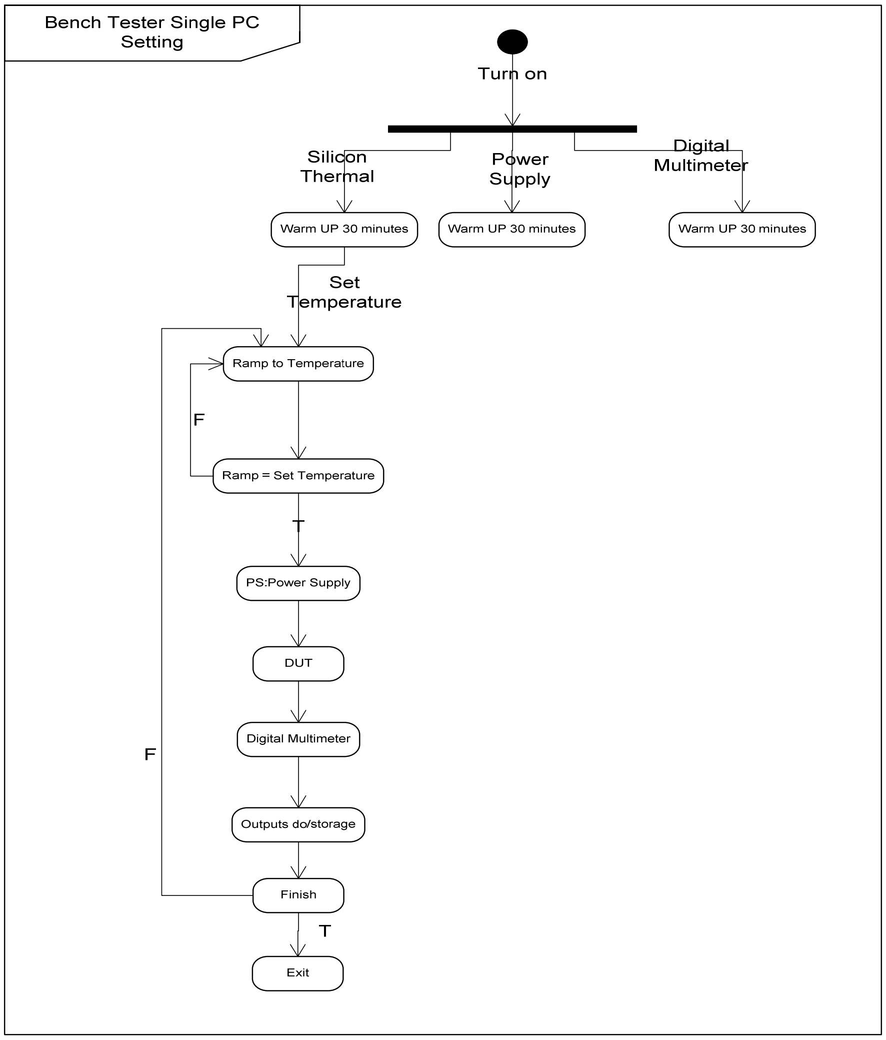


FIGURE 60 BENCH TEST STATE MODEL

4.3.3 Interaction Model

Interaction modeling is the last UML technique used in this project. As a quick review, the class model describes the objects in a system and their relationships, the state model describes the temporal behavior of these objects, and the interaction model describes how the objects interact to produce a practical result. [63] The interaction model can be separated into three components [64]:

- Use Cases describe how the system interacts with outside actors.
- Sequence Diagram is more detail and show messages exchanged between objects.
- Activity Diagram which can show data and/or control flows to implement a process.

The test environment is placed into a default state. This process is achieved by initializing the communication protocol, selecting the type of chip to test, resetting the chip, initializing the serial communication, and setting peripherals to default value. This is done both manually and through software. In the following section, the Use Description and Use Diagram for all equipment and chips are displayed.

Use Case: Initialize HP3468 Tri-State Power Supply

Summary: The software is initialized to communicate to the power supply by setting the appropriate GPIB address.

Actors: Test Engineer

Preconditions: The GPIB address has been manual set using the front panel on the power supply to be 5.

Description: Pressing the “Initialize Power Supply Button” place the soft panel to initialize power supply. The GPIB address box should be set to same address as the actual power supply in this case 5. “Start” creates the handle to the appropriate GPIB address that is use in all communication to the power supply. “Power Setting” will bring back into focus the power supply setting panel.

Exceptions: If the power supply is not on, the GPIB will display an error that there is no device at that address.

Postconditions: The power supply is waiting for communication from the host program. Remote indicator shows on front panel of the power supply.

Use Case: Setup HP3468 Tri-State Power Supply

Summary: The power supply sets the voltage and current level to the evaluation board that chip is mounted on. There are three different settings for each measurement. There can be a maximum of ten settings for each of the three tri-state inputs.

Actors: Test Engineer

Preconditions: The GPIB address is already set to 5. The power supply is on and has been soaking in the on state for at least an thirty minutes. It is now waiting for source values.

Description: The instrument starts in a waiting state that only displays the voltage values of 0.00, current value of 0.00, and no remote state. When the test engineer presses the power supply button the setup, the power supply soft panel become active. The test engineer can set up to ten volts and current values for 6, 25, and -25 volt range. The test engineer sets output state and tracking off and then press “auto-power setup” to enter the values in the data structure.

Exceptions: If the power supply is not on, the GPIB will display an error that there is no device at that address. Voltage and current out of range will automatically be set to the highest possible value.

Postconditions: The power supply is waiting for communication from Automation program.

Use Case: Initialize Silicon Thermal

Summary: The software initializes communication with the “Silicon Thermal”. The “Silicon Thermal” adjusts the DUT temperature.

Actors: Test Engineer

Preconditions: The Silicon Thermal is turned on and waiting for communication to the host computer.

Description: Sets the address for the RS485 serial port. Set up the serial port for communication between the host and silicon thermal. Set the Silicon Thermal in a known state like Celsius over Fahrenheit and others. Set the Silicon Thermal decimal point values. Check connections.

Exceptions: Silicon Thermal off error no device at address. It no write to device was established pop-up panel will say “Did not write to device”.

Postconditions: Silicon thermal is waiting for temperature setting commands.

Use Case: Initialize Chip CDB533x.exe

Summary: Places the communication bus and the chip in a known state.

Actors: Test Engineer / Tester

Preconditions: The tester board is plugged into the USB port of the computer. Power is supplied to the banana plugs on the evaluation board which powers the chip and other microchips mounted to the board.

Description: Highlight the box on the interface panel that corresponds to the interface protocol being used, (USB or read from a file). Select the chip being tested. Press button to initialize the serial port and then press button to reset the device.

Exceptions: Buffer overrun error if the device is not connected to universal serial bus or not power up. If wrong chip selected, reset will not initiate.

Postconditions: Chip is ready to receive commands from the host.

Use Case: Single Measurement Eval553x.exe

Summary: This application sets chip registers, allows for offset to be calculated and reads the output from the DAC of the chip. The output from the DAC is plotted in time domain, frequency and/or histogram. Several important test parameters are calculated: maximum and minimum values, S/PN, SINAD, S/D, SNR, mean, STD_DEV, and variance.

Actors: Test Engineer / Tester

Preconditions: The tester board is plugged into USB port of the computer. Necessary power is supplied to the testing board to power the components on the chip and the board itself. Power supply is enabled for the device.

Description: Set the configuration register, (Power Consumption, System Reset Sequence, Input Short, Voltage Reference, Offset and Gain Select, and etc. Run calibration and set offset and gain register per channel. Perform single or continuous conversion. Calculate chip electrical characteristic parameters and plots.

Exceptions: Error or buffer overrun from USB port. Send following message to the user to “reset the board by pressing the reset button on the board and application. Also, if this second time, then user should power down the board”.

Post conditions: Board is still powered up and connected to the USB port of the computer. Chip is in command mode and waiting for the next operation.

Use Case: Automation Eval553x.exe

Summary: Storage of power supply and “Silicon Thermal” setting in data structure. Storage of chip registers value in data structures. Run test automatically without operator supervision.

Actors: Test Engineer / Tester

Preconditions: Board is power up. The serial port and chip have been reset. The chip is in command mode and waiting.

Description: Up to ten temperatures and thirty different voltage and current settings are first stored. The DUT register values are stored into data structure. The tester presses Automation on the bench test panel and the characterization process begins. All output parameters and settings are stored into a spreadsheet file format.

Exceptions: Each register values written to the device is read back for verification. If the decode value is not correct, the program will attempt to rewrite to the register three times. If a USB error occurs, the serial port and device under test is reset and the program continues.

Postconditions: Board is powered up and the chip is in command mode. The serial port and chip is reinitialized to a known state.

Figure 61-63 are the Use Case diagrams for cases above. There are two principal actors: test engineer and tester. The test engineer designs the test to be implemented, which consists of DUT register setting, voltage and current values, and device temperatures. The tester is a technician or some worker that only runs the test.

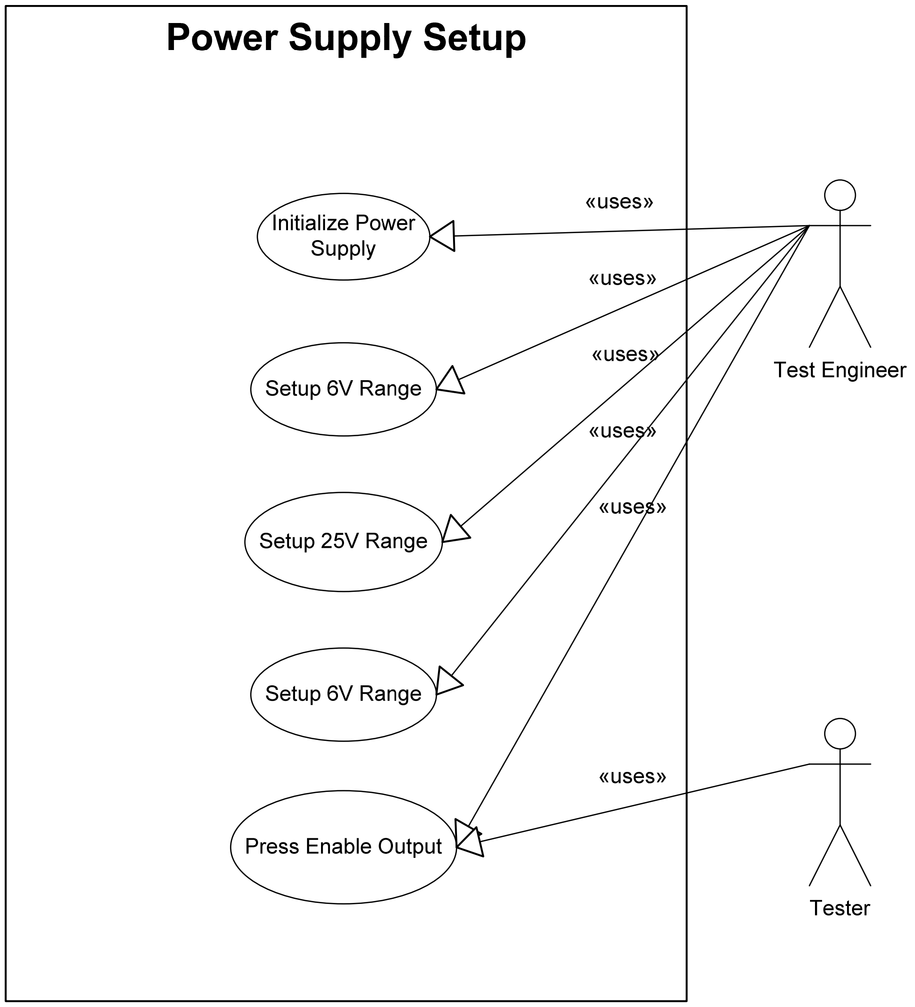


FIGURE 61 USE CASE DIAGRAM FOR POWER SUPPLY

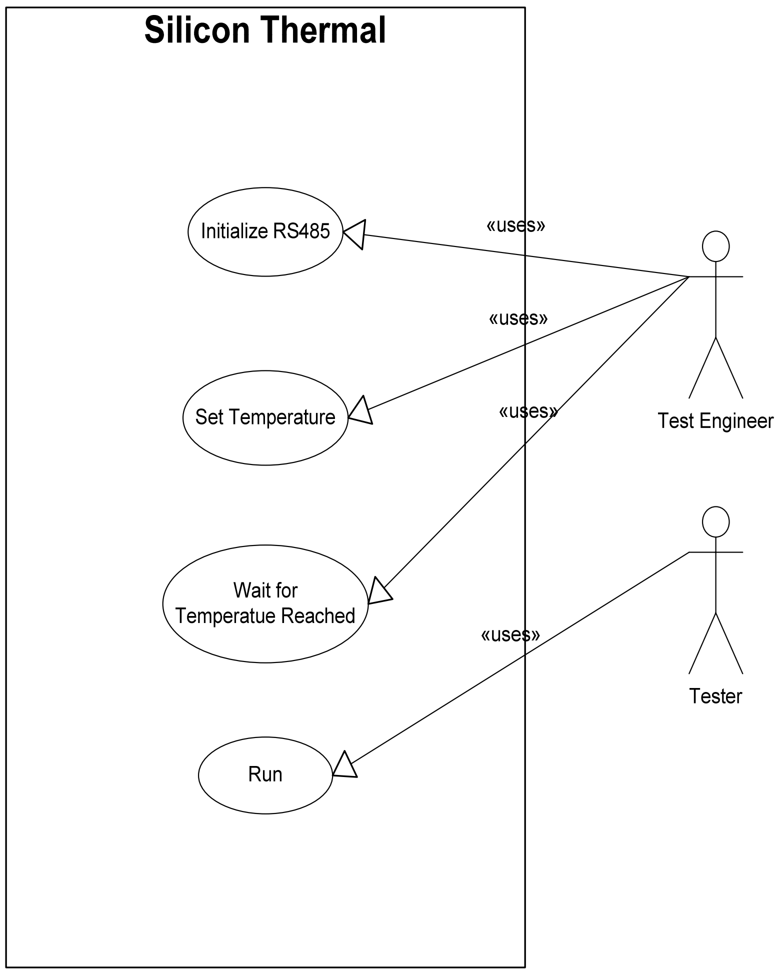


FIGURE 62 SILICON THERMAL USE CASE DIAGRAM

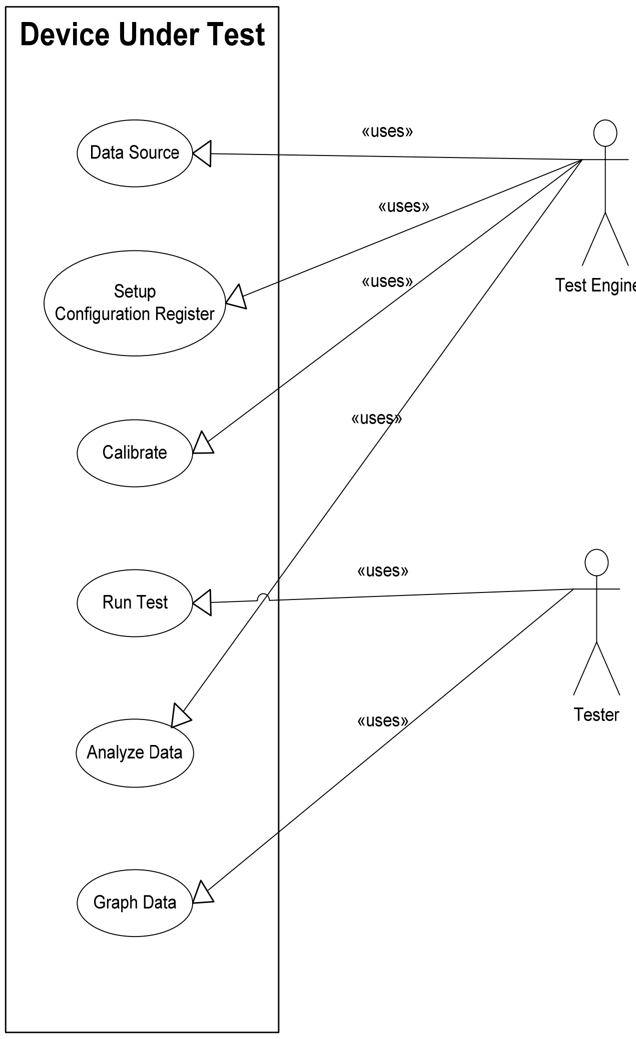


FIGURE 63 DUT USE CASE DIAGRAM

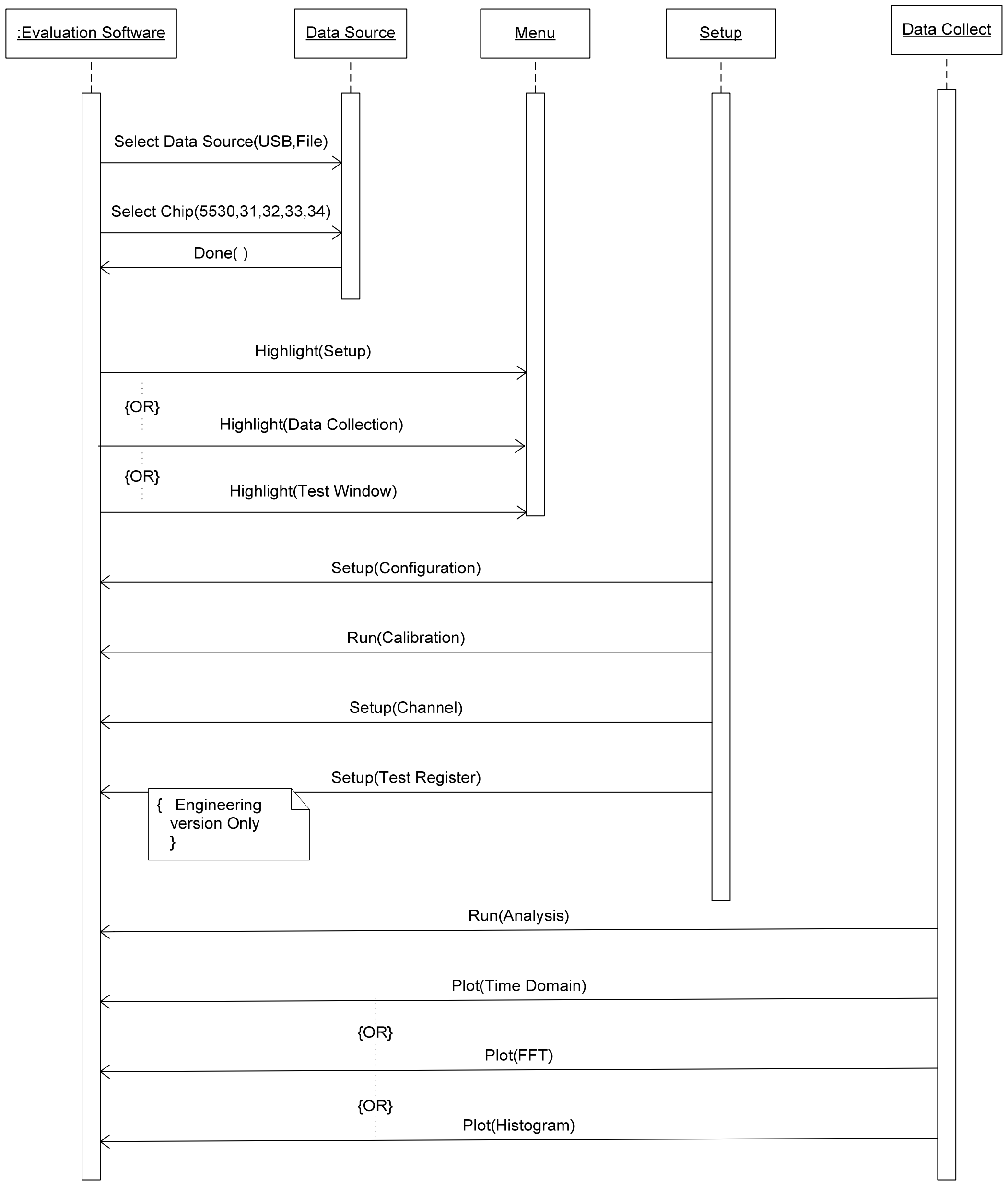


FIGURE 64 EVALUATION SOFTWARE SEQUENCE “EVAL553X_U.EXE”

Figure 64 is the sequence diagram for the evaluation software that customers can download from the website. There are two versions: engineering and customer. The object represents different panels that the user sees when the application is executed. The data source configuration panel determines whether the data source is collected through the USB or from a file. The setup panel is used to configure different registers and conversion modes for the ADC. The test setup register is a panel that is only included in the engineering version. The data collection panel runs the analysis and determines the output parameter calculated based on the plot being used.

4.4 Automation Test Environment

The Automation program is the top level program in the automatic test environment. It controls the power supply, silicon thermal program, digital multimeter, and evaluation software. The Automation program interfaces with the lower level program through a panel in the evaluation software. It is one of the menu selections within “Bench Test”. The user sets the values to the chip and the peripherals. The values are stored in arrays of data structure corresponding to the peripherals and chip being used in the test. Figure 65 is a layout diagram of the Automation architecture.

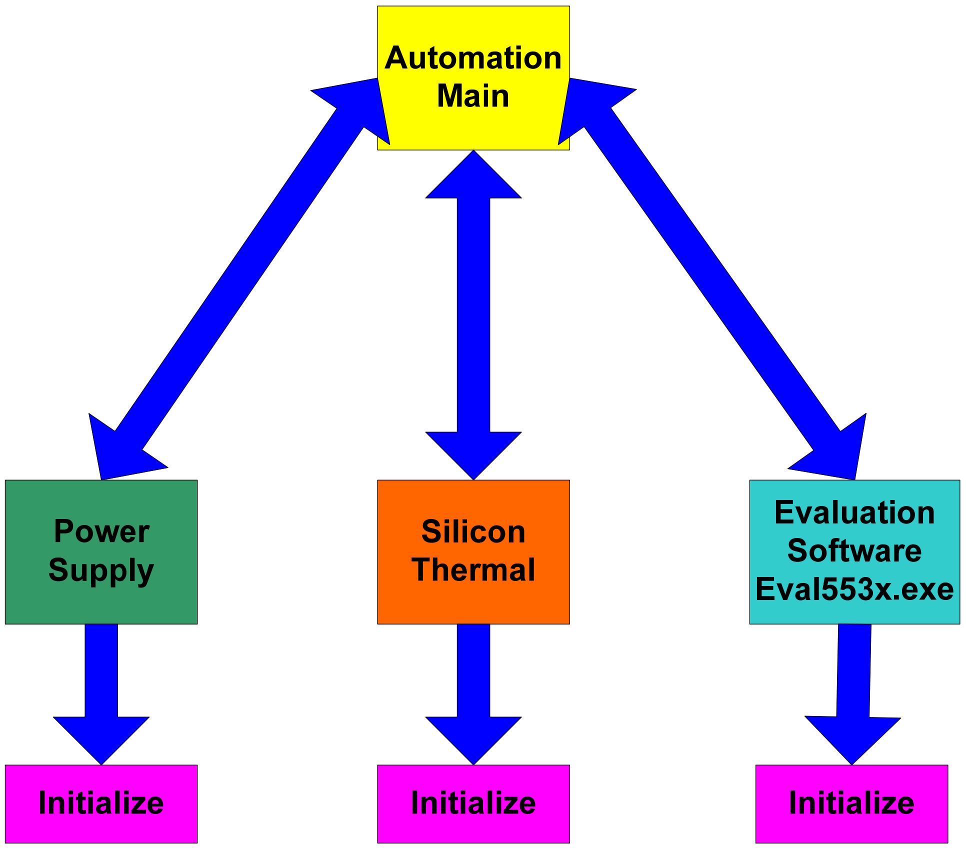


FIGURE 65 AUTOMATION LAYOUT

4.4.1 Class Model

The Automation class is an abstract class. Figure 66 is a diagram of the class model. The green represents the object in the chip that is to be configured, the light blue represents the peripheral power supply and multimeter, and the yellow represents the silicon thermal. For each class there is an operation called storage. It is the method used to store the values of the chip and peripherals for automation.

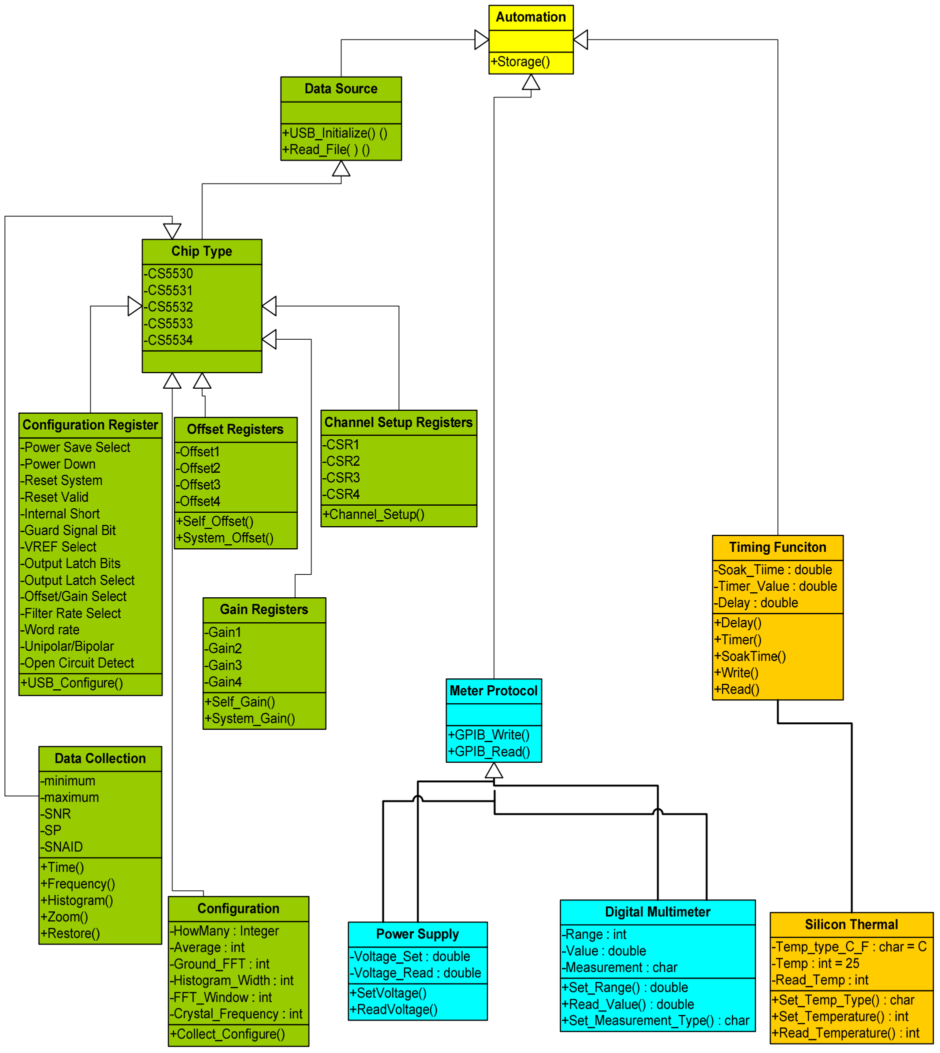


FIGURE 66 AUTOMATION CLASS MODEL

4.4.2 State Model

Automation State model for chip and peripherals is diagramed below. Each diagram has a state called “Store Values”. These state stores fix number values in an array.

State: Initializing Power Supply

Description: initialize communication between power supply

Event sequence that produces the state:
press “Power Supply” button Autosetpanel.uir
press “Initialize Power Supply” Button on Power Supply Setup.uir

Conditions that characterize the state:
change the “GPIB address” field
press start to initialize communication

Events accepted in the state:

event	**response**	**next state**
(Automation)		
buttonPushed(Power Supply)	change “all”	waiting
enter numeric values	change values	waiting
press Start		
press PowerSetting panel	change interface	PowerSupply setup

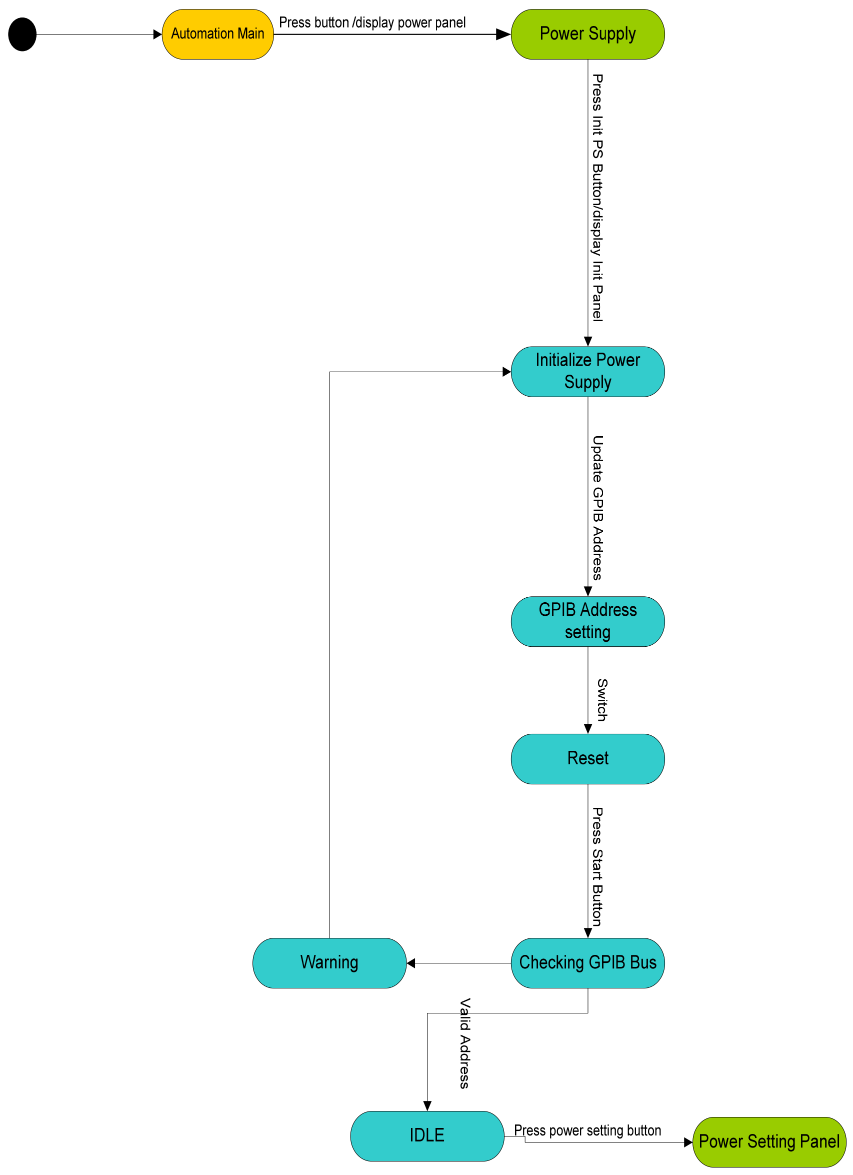


FIGURE 67 AUTOMATION POWER INITIALIZATION STATE MODEL

State: Setting Power Supply’s voltage and current

Description: initialize communication between power supply

Event sequence that produces the state:
Press “Power Supply” button Autosetpanel.uir

Condition that characterize the state:
Change the voltage and current value by pressing the up and down arrow
Press Auto-power setup to store values in class states.

Events accepted in the state:

event **(**Automation)	**response**	**next state**
buttonPushed(Power Supply)	power interface popups	waiting
enter numeric values	change values	
waiting		
buttonPushed(Auto-Power Setup)	store values	waiting
buttonPushed(Automation Main)	returns to Autosetpanel interface	waiting

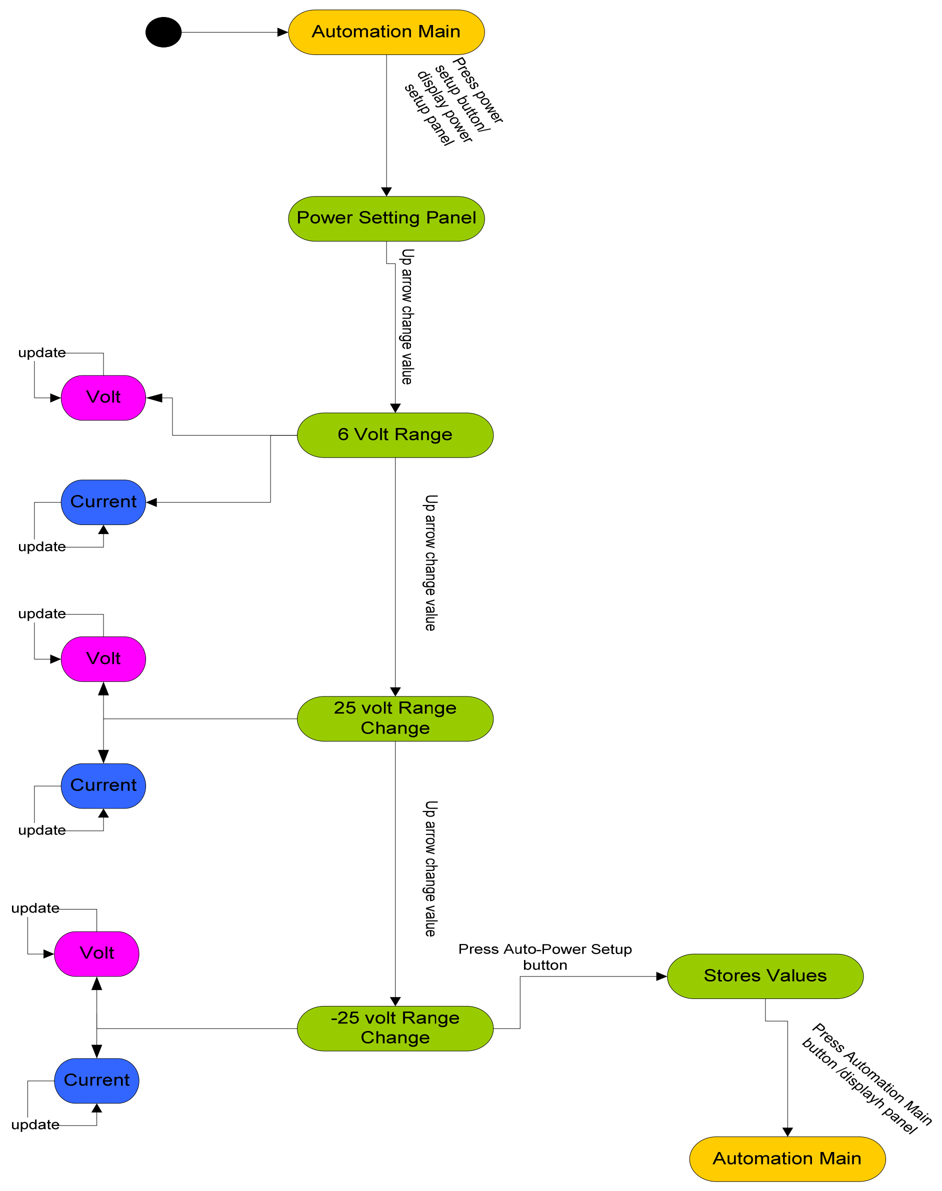


FIGURE 68 SETTING POWER SUPPLY VOLTAGES AND CURRENT VALUES

State: Setting temperature values of device being tested

Description: initializes communication with the Silicon thermal that set the temperature and stores the temperature values in member function of class

Event sequence that produces the state:
Press “Power Supply” button Autosetpanel.uir

Condition that characterize the state:
Change the voltage and current value by pressing the up and down arrow
Press Auto-power setup to store values in class states.

Events accepted in the state:

event	**response**	**next state**
(Automation)		
buttonPushed(Power Supply)	power interface popups	waiting
enter numeric values	change values	waiting
buttonPushed(Auto-Power Setup)	store values	waiting
buttonPushed(Automation Main)	returns to Autosetpanel interface	waiting

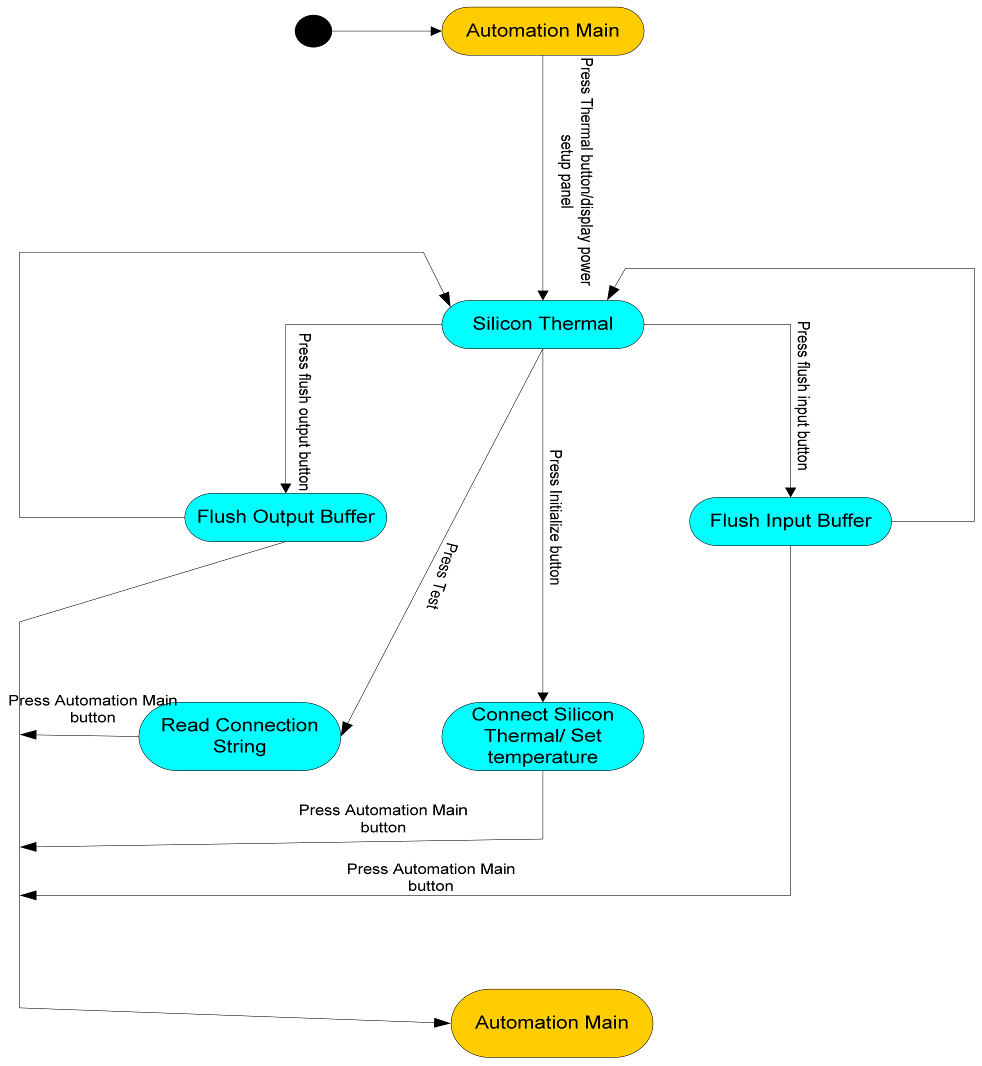

Automation Main
Press Thermal button/display power setup panel
Silicon Thermal
Press flush output button
Press flush input button
Press Initialize button
Press Test
Flush Output Buffer
Flush Input Buffer
Press Automation Main button
Read Connection String
Connect Silicon Thermal/ Set temperature
Press Automation Main button
Press Automation Main button
Automation Main

FIGURE 69 SILICON THERMAL TEMPERATURE VALUES

4.4.3 Interaction Model

In the following section, the interaction model for the automation process is diagramed. The test engineer is the individual that configures the test for chip characterization and analysis. The tester job is to run and monitor the test, which can take hours or even days. Figure 70 displays the relationship between the test engineers, the testers, and the automatic test environment.

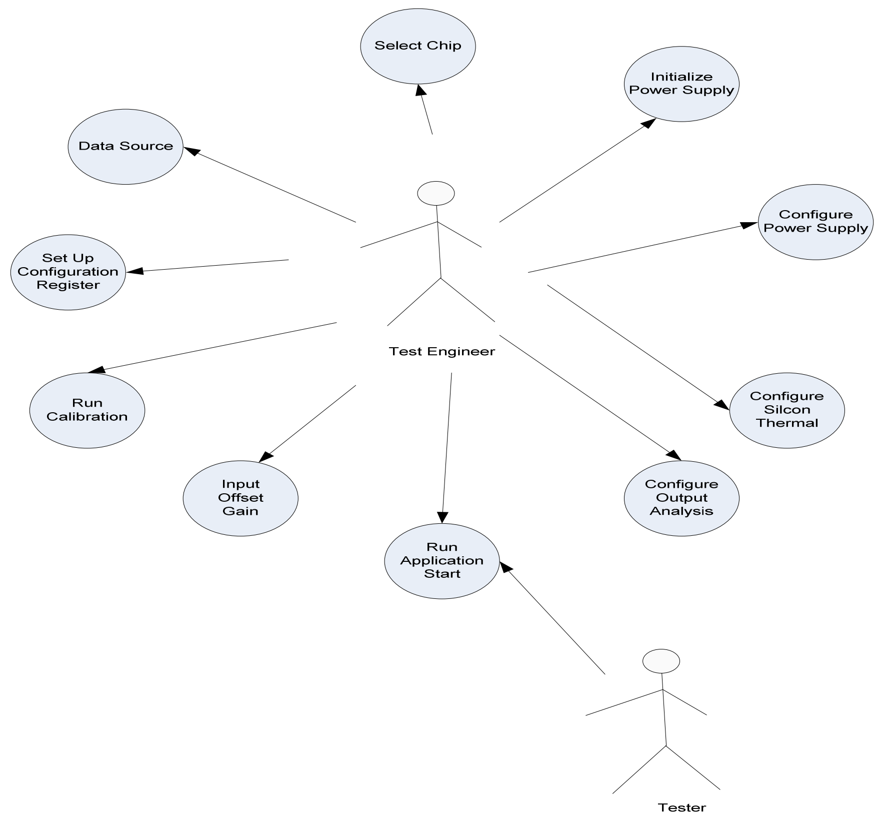


Figure 70 Test Engineers and Testers Relationship to Automatic Test Environment

CHAPTER 5

IMPLEMENTATION

INTRODUCTION

I programmed this project using a C-base integrated development environment called LabWindows produced by National Instrument. It is an ANSI C based development environment that provides a comprehensive set of programming tools for creating test and control applications. It combines the longevity and reusability of ANSI C with engineering-specific functionality for instrument control, data acquisition, analysis, and user interface development. [64] The interface is event driven. Event examples are: commit (press enter), change value, focus, and mouse over object and so on. I am using LabWindows version 8 designed for Windows. However, there is a Linux kernel version for Red Hat WS4, WS3 and others. [65] The microcontroller code is written using Silicon Labs API drivers with their microcontroller development environment USBExpress which is used to download and debug code running in the microcontroller. The host (PC) uses several protocols to communicate with chip and test environment. The USB communicates with the microcontroller and it in turn, communicates with the chip using SPI interface. The host uses GPIB and RS485 to communicate with the peripherals creating the test environment.

5.1 PROTOCOLS

5.1.1 SPI

The SPI bus is a standard developed by Motorola. [66] It is used to communicate with devices like EEPROMs, real-time clock, converters (ADC and DAC), and sensors. SPI bus is made up of four wires for full-duplex serial interface. Three wires are SCK (serial clock), MOSI (master out slave in), and MISO (master in slave out). The fourth wire is CS (chip select). [66] The communication across the SPI uses a system of data exchange. [67] Whenever a bit is written to an SPI device across the MOSI lines, the SPI device concurrently returns a bit to the MISO line. The data is transferred in both directions. It is up to the receiving device to determine whether the receiving data is useful or not. For example, to receive information from the ADC, the master (host) must configure the ADC to send n bytes of data. The host must then send n bytes for the exchange of valid data. These bytes can be anything since they are only used to clock the data out of the receiving device. There are two other parameters: clock polarity (CPOL) and clock phase (CPHA). Because the SPI has no acknowledgement mechanism or flow control, the SPI master has no way of knowing whether the slave has received a data byte correctly or even whether the bus is connected. For this reason, I wrote a decode function to make sure the registers are configured properly.

5.1.2 GPIB

Hewlett-Packard originally developed the interface called HP-IB for connecting and controlling programmable instruments. It later became known as IEEE-488, a standard interface for communicating between instruments from different sources. This was later called GPIB (General Purpose Interface bus) because of its popularity in the computer industry. Any instrument can use the IEEE-488 specification since it defines the interface not the function of the instrument itself or the form of the instrument's data. The instrument does not have complete control of the interface. The host or active controller of the bus tells the interface what to do. [68] The IEEE-488 interface system consists of 16 signal lines and 8 ground lines. The 16 lines are divided into 3 groups (8 data lines, 3 handshake lines, and 5 interface management lines). The IEEE-488 cable has both a plug and receptacle connector on both ends. Devices can be daisy-chained linearly or in a star configuration. The maximum number of devices in a configuration is 20. The maximum separation between devices is 4 meters. There are two standards: IEEE-488.1 and -488.2. The differences are that -488.1 do not address data formats, status report, message exchange protocols, common configuration commands or device specific commands. [69]

5.1.3 RS485

RS-485 is a version of RS-232. RS-232 is a serial port or may be better known as the COM port. [70] RS-232 is a three wire communication setup. One wire is used for transmissions, another receives, and another grounds. With RS-232 there is a single device-to-device connection. Only one device can be connected through a given com port. RS-485 is an addressable version of serial port, which means that one com port can communicate to several devices. [71]

5.1.4 Peripherals Interfacing

In the following section I will explain sample code showing different methods of communicating with peripherals and the chip.

The power supply used in this project is triple volts DC power Supply, HP E3631A. The communication protocol is GPIB. The function below performs the following initialization actions:

- Opens a session to the default resource manager and a session to specified device using the interface and address specified in the resource name control
- Performs an identification query on the Instrument

- Resets the instrument to a known state
- Sends initialization commands to the instrument turn Headers Off, Short Command form, and Data Transfer Binary
- Returns an instrument handle, which is used to differentiate between different sessions of this instrument driver
- Each time this function is invoked a unique session is opened.

The function prototype is:

```
extern ViSession instrumentHandle;

ViStatus hpe363xa_init (ViRsrc Resource_Name,ViBoolean, ID_Query,
ViBoolean Reset_Device, ViSession *Instrument_Handle);

ViStatus _VI_FUNC hpe363xa_init (ViRsrc resourceName, ViBoolean IDQuery,
                ViBoolean resetDev, ViPSession instrSession)
{
   ViStatus hpe363xa_status = VI_SUCCESS;
   ViSession rmSession = 0;
   ViUInt32 retCnt = 0;
   ViByte rdBuffer[BUFFER_SIZE];

   /*- Check input parameter ranges ----------------------------------------*/
   if (hpe363xa_invalidViBooleanRange (IDQuery))
      return VI_ERROR_PARAMETER2;
   if (hpe363xa_invalidViBooleanRange (resetDev))
      return VI_ERROR_PARAMETER3;

   /*- Open instrument session ---------------------------------------------*/
   if ((hpe363xa_status = viOpenDefaultRM (&rmSession)) < 0)
      return hpe363xa_status;
   if ((hpe363xa_status = viOpen (rmSession, resourceName, VI_NULL,
VI_NULL, instrSession)) < 0) {
      viClose (rmSession);
      return hpe363xa_status;
   }

   /*- Configure VISA Formatted I/O ---------------------------------------*/
   if ((hpe363xa_status = viSetAttribute (*instrSession, VI_ATTR_TMO_VALUE,
10000)) < 0)
         return hpe363xa_initCleanUp (rmSession, instrSession,
hpe363xa_status);
   if ((hpe363xa_status = viSetBuf (*instrSession,
VI_READ_BUF|VI_WRITE_BUF, 4000)) < 0)
         return hpe363xa_initCleanUp (rmSession, instrSession,
hpe363xa_status);
   if ((hpe363xa_status = viSetAttribute (*instrSession,
VI_ATTR_WR_BUF_OPER_MODE,
                     VI_FLUSH_ON_ACCESS)) < 0)
         return hpe363xa_initCleanUp (rmSession, instrSession,
hpe363xa_status);
   if ((hpe363xa_status = viSetAttribute (*instrSession,
VI_ATTR_RD_BUF_OPER_MODE,
                     VI_FLUSH_ON_ACCESS)) < 0)
         return hpe363xa_initCleanUp (rmSession, instrSession,
hpe363xa_status);

   /*- Identification Query ----------------------------------------------*/
   if (IDQuery) {
      if ((hpe363xa_status = viWrite (*instrSession, "*IDN?", 5, &retCnt)) < 0)
         return hpe363xa_initCleanUp (rmSession, instrSession,
hpe363xa_status);
      if ((hpe363xa_status = viRead (*instrSession, rdBuffer, BUFFER_SIZE,
&retCnt)) < 0)
         return hpe363xa_status;

      Scan (rdBuffer, "HEWLETT-PACKARD,E3631A");
      if (NumFmtdBytes () != 22){
         Scan (rdBuffer, "HEWLETT-PACKARD,E3632A");
         if (NumFmtdBytes () != 22)
            return hpe363xa_initCleanUp (rmSession, instrSession,
VI_ERROR_FAIL_ID_QUERY);
      }
   }
   /*- Reset instrument --------------------------------------------------*/
   if (resetDev) {
      if ((hpe363xa_status = hpe363xa_reset (*instrSession)) < 0)
         return hpe363xa_initCleanUp (rmSession, instrSession,
hpe363xa_status);
   }
   else  /*- Send Default Instrument Setup -------------------------------*/
      if ((hpe363xa_status = hpe363xa_defaultInstrSetup (*instrSession)) < 0)
         return hpe363xa_initCleanUp (rmSession, instrSession,
hpe363xa_status);

   return hpe363xa_status;
}
```

The following function prototype is used to configure the power supply voltage, current out, tracking mode, and coupling.

ViStatus hpe363xa_configOutput3631 (ViSession Instrument_Handle, ViBoolean Outputs, ViBoolean Tracking);

In the following snippet of code, the 6-volt range of the power supply in the outer loop. In the inner loop I am setting plus and minus 25-volt range of the power supply. The plus and minus voltage should be the same value but opposite polarity.

```
hpe363xa_configOutput3631 (instrumentHandle,plus6Range.outputstate
,plus6Range.tracking);
 for(istartThermal = 0; istartThermal < 3; istartThermal++)
 {
          SiThermal(istartThermal);
           for (istart= 0; istart < plus6Range.howmany; istart++)
           {
```

```
        hpe363xa_configCurrVolt3631                              (instrumentHandle,
0,plus6Range.voltage[istart] ,  plus6Range.current[istart]);
        Delay(0.15);
        hpe363xa_configCurrVolt3631                              (instrumentHandle,
1,plus25Range.voltage[istart] , plus25Range.current[istart]);
         Delay(0.15);
         hpe363xa_configCurrVolt3631                             (instrumentHandle,
2,minus25Range.voltage[istart] ,minus25Range.current[istart]);
         Delay(0.15);
         StartProcess();
           }

}
```

The output current is set to the maximum for each of the voltage outputs.

The Keithley 197A is a digital multimeter that reads the voltage value across the chip. The Keithley is configured and read through the GPIB protocol. The following function prototype is use to initialize the Keithley. The initialization process does the following:

- clears the instrument with a GPIB device clear command
- sets the instrument to a known state based on factory default settings
- queries for the ID of the instrument
- reads the measuring function that is selected on the front panel
- checks to see if the dB mode is enabled

```
void kei197a_init (int);
```

The following function reads the voltage or current value displayed on the digital multimeter.

```
void kei197a_queryMeasurementFunction (function_name, function_code)
```

The Silicon Thermal is configured through the RS-485 port. It is used to set the temperature of the chip being tested.   To meet ISO 9000 specifications the chip must meet designed specification at different temperatures. The Silicon Thermal is initialized with the following function. The initialization process sets the temperature mode (C / F), whether a decimal point is used, and default temperature. The default temperature is first manually dialed into the silicon thermal through an interface panel.

```
int CVICALLBACK initstCB (int panel, int control, int event,void *callbackData, int
eventData1, int eventData2)
{

        /*Initialization Commands */
        char *LORE = "L32040029";
        char *TempCel = "L32025B0001005F";
        char *DecimalPoint = "L32025C00010060";
        int stringsize, numBytesWrittenStart,numBytesWrittenEnd;

        switch (event)
                {
                case EVENT_COMMIT:
                                OpenComConfig (1, devicename, 9600, 0, 8, 1, 512,
512);
                                numBytesWrittenStart = ComWrtByte (1, 2);
                                stringsize = StringLength (LORE);
                                if (ComWrt (1, LORE, stringsize) !=stringsize)
                                        {
                                          MessagePopup ("DID not write", "did not
serial write");

                                        }

                                numBytesWrittenEnd = ComWrtByte (1, 3);



                                /*Set Temperature to Celsius */
                                numBytesWrittenStart = ComWrtByte (1, 2);
                                stringsize = StringLength (TempCel);
                                if (ComWrt (1, TempCel, stringsize) !=stringsize)
                                        {
                                          MessagePopup ("DID not write", "did not
serial write");

                                        }
                                numBytesWrittenEnd = ComWrtByte (1, 3);

                                /*Set the Decimal Point */
                                numBytesWrittenStart = ComWrtByte (1, 2);
                                stringsize = StringLength (DecimalPoint);
                                if (ComWrt (1, DecimalPoint, stringsize) !=stringsize)
                                    {
                                      MessagePopup ("DID not write", "did not
serial write");

…
```

The command to set the specific temperature is :

```
void SiThermal(int commandindex )
{
        char *tempcomm[3] =
{"L3202000400104C","L3202000250004E","L32020009000050"};
        int numBytesWrittenStart,
numBytesWrittenEnd,stringsize,inqlen,bytes_read;



            /*Temperature*/
                numBytesWrittenStart = ComWrtByte (1, 2);
                stringsize = StringLength ( tempcomm[commandindex]);
                    if (ComWrt (1,  tempcomm[commandindex],
stringsize) !=stringsize)
```

```
                                        {
                                          MessagePopup ("DID not write", "did not
serial write");

                                        }
…
```

The silicon thermal command instruction is very complex to program. The command includes a checksum within the temperature value to determine if the command is valid. It sends an error if the checksum does not match correctly.

There are two protocols used to configure and retrieve data from the chip. The microcontroller is the bridge between the computer and the chip tested. The microcontroller acts as a language interpreter converting USB format commands between the computer and microcontroller to SPI format commands used to control and read data from the chip. The following is an example code between the computer and the microcontroller using Silicon Labs USB_API interface:

```
stat = F32x_Write(cyHandle, wBuffer, BytesToWrite, &BytesWritten);
if  (stat)
{
        MessagePopup("Error Message", "USB Error - Unable to send read
request command.");
        return stat;
```

```
}


do
{
        stat =  F32x_CheckRXQueue(cyHandle,                 &NumBytesInQueue,
&QueueStatus);
        if  (stat)
        {
                MessagePopup("Error Message", "USB Error - Unable to determine
queue status.");
                return stat;
        }
        if(count < 1000)  //rm 04-20-06
        {
                count++;
        }
        else
        {
                MessagePopup ("Queue Not Ready", "USB Queue Not ready");
                count = 0;
                break; stat;
        }

                Delay (.0001);

}
while (! (QueueStatus & 0x00000002)); //"RX_COMPLETE" FLAG
```

F32_Write( ) writes the six byte character to the USB port. The F32x_CheckRXQueue( ) checks the receive queue to see if information has been sent from the chip to the microcontroller. The NumbytesInQueue variable contains the number of bytes in the queue. The QueueStatus variable holds the status of the queue. When the queue has been emptied it returns 0x02. This causes the program to exit from the do_While loop.

The microcontroller sends the command across the SPI port to the chip. The microcontroller uses USB Interrupt to get the USB port's attention. The following are snippets of the microcontroller code:

```
void USB_HAN(void) interrupt 16  //USB INTERRUPT HANDLER
{
        BYTE INTVAL = Get_Interrupt_Source();  //clears ALL USB pending flags
        if (INTVAL & TX_COMPLETE)
                {
```

```
                TXFL = 1;
                }
        if (INTVAL & RX_COMPLETE) //Micro has received an entire
"Out_Packet" from PC
                {
                Block_Read(Out_Packet, 6);      //Max Block_Read is 64 bytes,
PC sends 6-byte packets
                switch(Out_Packet[0])
                        {
                        case 0x01:
                        case 0x02:
                        case 0x03:
                        case 0x05:
                        case 0x07:
                        case 0x11:
                        case 0x12:
                        case 0x15:
                        case 0x21:
                        case 0x22:
                        case 0x25:
                        case 0x31:
                        case 0x32:
                        case 0x35:
                        WRFL = 1;
                        break;
…
```

```
While(1)
if(SCFL)   //single convert mode (may require 0.6 seconds)
                    {
                    pac_z = Out_Packet[0];
                    DUT_CSB = 0;                                    //lower Chip Select
                    while(TXBMT == 0);//check Tx buffer empty
                    SPIF = 0;                          //clear "shift finished" flag
                    SPI0DAT = pac_z;   //shift out 80,88,90,98,A0,A8,B0, or B8
command
                    while(!SPIF);                      //Wait for SPI shift complete
                    while(RDYB);          //wait for SDO to drop (P1.2)
                    SPIF = 0;
                    SPI0DAT = 0x00;    //shift out zero to clear "SDO FLAG"
                    while(!SPIF);
                    SPIF = 0;
                    SPI0DAT = 0xFE;
                    while(!SPIF);
                    In_Packet[3] = SPI0DAT;   //Read SPI input buffer MSB
                    SPIF = 0;
                    SPI0DAT = 0xFE;
                    while(!SPIF);


…
```

USB_Han(Void) is the USB interrupt handler. It uses interrupt 16. When a command is being sent from the host to the chip, or when conversion data is ready to be uploaded to the computer this interrupt is enable.

“while(1)” represents a thread that is run continuously within the microcontroller. Each pass through the While statement the following flags are checked:

- SCFL - single convert mode
- IDFL - identify the microcontroller code
- RSFL - reset the serial port
- WRFL - write to register
- RDFL - read register
- UDFL - read offset or gain or channel setup registers
- CCFL - continuous conversion mode
- CLFL - clear chip

The chip commands are in hexadecimal code. When one of these codes matches a case statement, a flag is set. In the While statement, low level functions are used to serially transmit the data to and from the chip.

Out_Packet[0] is the command to be serialized. It is a byte in size. DUT_CSB selects the chip to write to by lowering the CS line to the chip. SPIF is the serial port shift finished flag. It is set to zero before each shift. SPIODAT serially shifts the command out bit by bit. The microcontroller sets the SPIF to one when it has finished, “while(!SPIF)”, and moves to the next statement. When the chip has completed a conversion, the SDO line is set low signaling there is data ready to be read by the controller, ”while(RDYB)”. RDYB is set to zero when this occurs and the controller advances to the next statement. The shift complete flag is set to zero and 0x00 is shifted to the chip making sure it is in single conversion mode. Conversion from the chip is shifted into the controller through In_Packet array. SPI0DAT contains eight bits which means that for the controller to read those eight bits it must send out eight bits. SPI0DAT = 0xFE does that.

Automation is accomplished through the use of For-Loops. The data structures used are arrays, and arrays of structures. Structures are used instead of classes because LabWindows is based on ANSI-C. The outer For–Loop controls the chip temperature by calling the Si_Thermal( ) function that takes an array of temperatures as input. The For-Loop inside controls the 6V range of the tri-volts power supply. The For-loop inside it controls the plus and minus 25V range of the tri-volts power supply. Within that For-loop there is the function that controls the device under test. The function is named DUT( ) which itself is composed of For-loop corresponding to the physical objects within the chip itself. The following is an example of the code being used.

```
For (temp = 0, temp < temp_array_size, temp++)
        Si_Thermal(temp_array[temp]);
```

```
For(ps6V = 0, ps6V <ps6V_array_size, ps6V++)
    Power_Supply(ps6V, ps_plus25V, ps_minus25V);
    For(ps25V= 0, ps25V < ps25V_array_size, ps25V++)
    {
        Power_Supply(ps6V, ps_plus25V, ps_minus25V);
        DUT(sChip);
    }
```

5.2 User Interface

In designing the user interface, my goals were to make it intuitive and easy to use. I followed these criteria:

1. When possible, the interface was designed to match the peripherals being used.
2. Interfaces were to closely resemble previous applications that testers and test engineers have used in the past.
3. Interface was grouped into blocks that had common physical events

Labwindows has a comprehensive suite of libraries and Window-based objects to use in developing applications. [72] For example, LabWindows contains Window like objects such as buttons, menus, panels, tables, and much more. Applications developed in LabWindows /CVI operate on the principle of event-driven programming. Event-driven programming executes segments of code, called callback functions in response to “event” -- the stimulus that occurs on the user interface. [73] These events can result from the objects on the panel or the panel itself. With event driven code, links between physical objects on the interface, like a command button, to a function are established. Every time an action is performed on the user interface control, an event is generated. LabWindows/CVI determines which control generated the event. The callback function associated with that control is invoked. In this section, I demonstrated the application interface and explained the design. In the Automation sections, I discussed the data structures used and how they operates.

Below is an example code of a callback function associated to interface control. This is the function called when the “Calibration” button is pressed. The event generated is “Event-Commit”.

```
int CVICALLBACK GO_CAL (int panel, int control, int event, void *callbackData,
int eventData1, int eventData2)
{
        int     offset_new[4], gain_new[4];
                switch (event)
                {
                        case EVENT_COMMIT:
                        if(!CS5530)
                        {
                                err = Fun_USB(0x49, 0, 0, 0, 0, number_of_bits,
                                offset_new);
                                if(err) break;
                                        DisplayOffset(panel, offset_new);
                                        err = Fun_USB(0x4A, 0, 0, 0, 0,
                                        number_of_bits, gain_new);
                                if(err) break;
                                DisplayGain(panel, gain_new);
                                DisplayPanel(pnl_cal);
                        }
                        else
                        {
                                err = Fun_USB(0x09, 0, 0, 0, 0, number_of_bits,
                                offset_new);
                                if(err) break;
                                DisplayOffset(panel, offset_new);
                                err = Fun_USB(0x0A, 0, 0, 0, 0, number_of_bits,
                                gain_new);
                                if(err) break;
                                DisplayGain(panel, gain_new);
                                DisplayPanel(pnl_cal);
                        }

                        break;
                }
        return 0;
}
```

The all function generated for a user interface device has a tag associated with it "CVICALLBACK". This is used by the compiler to identify LabWindows/CVI functions. The function arguments are:

1. int panel – identify the panel where the event occurred
2. int control – identify the control that created the event
3. int event – is the event that was generated
4. void *callbackData – is a generic pointer of data that can passed

The "switch" deciphers the event that occurred and runs the corresponding code. There can more then one type of event per user interface.

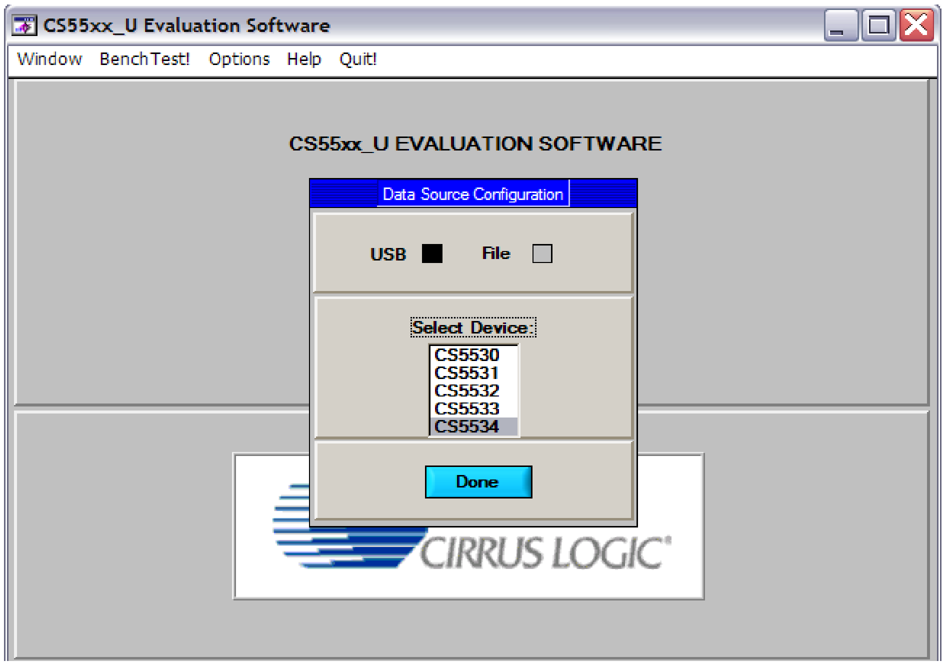
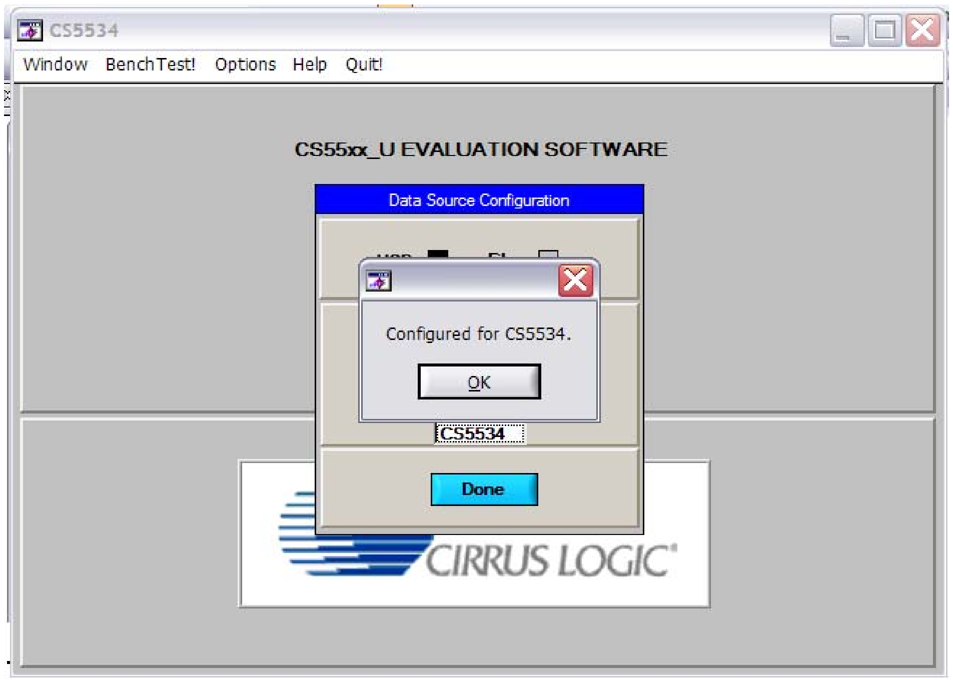


FIGURE 71 DATA SOURCE SELECTION

The first panel that appears when the application is executed is the "Data Source Configuration". From this panel a selection is made whether to receive data from the "USB" port or from a file. If "File" is selected as the source, then a directory window will pop up. The user can browse to select the file to be imported.

The ADC chip being characterized is then selected. When the chip is selected, the panels title changes from "CS55xx_U Evaluation Software" to chip being selected. For this example, I selected CS5534.



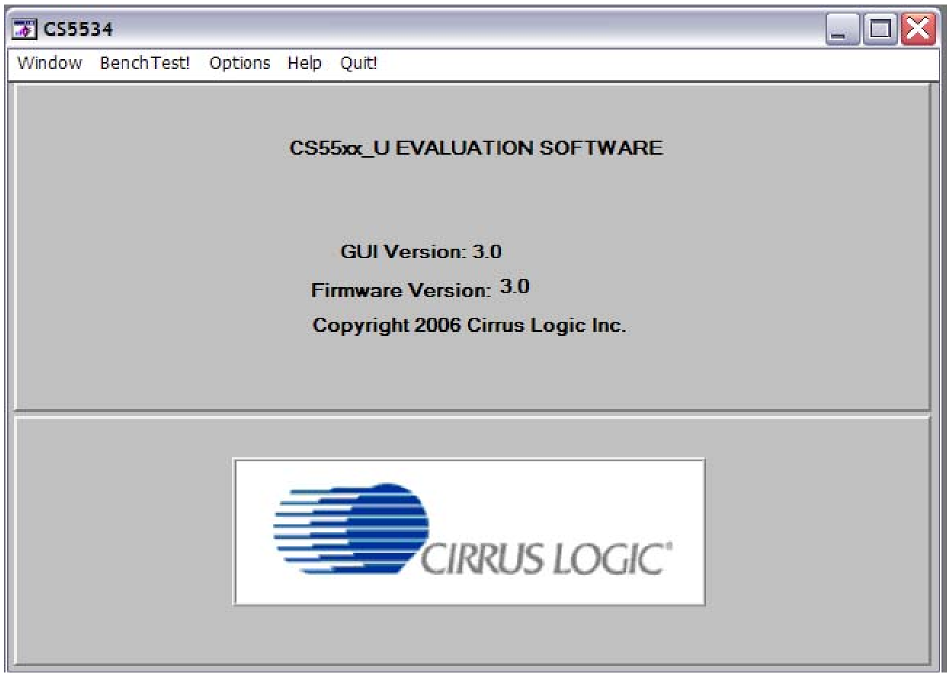
CS55xx_U EVALUATION SOFTWARE

Configured for CS5534.

CS5534

FIGURE 72 SUCCESSFUL COMMUNICATION

When “Done” is pressed, the following confirmation appears. If there is a failure, a message box appears saying “USB configuration failure”, “Check to USB connection.”



CS55xx_U EVALUATION SOFTWARE

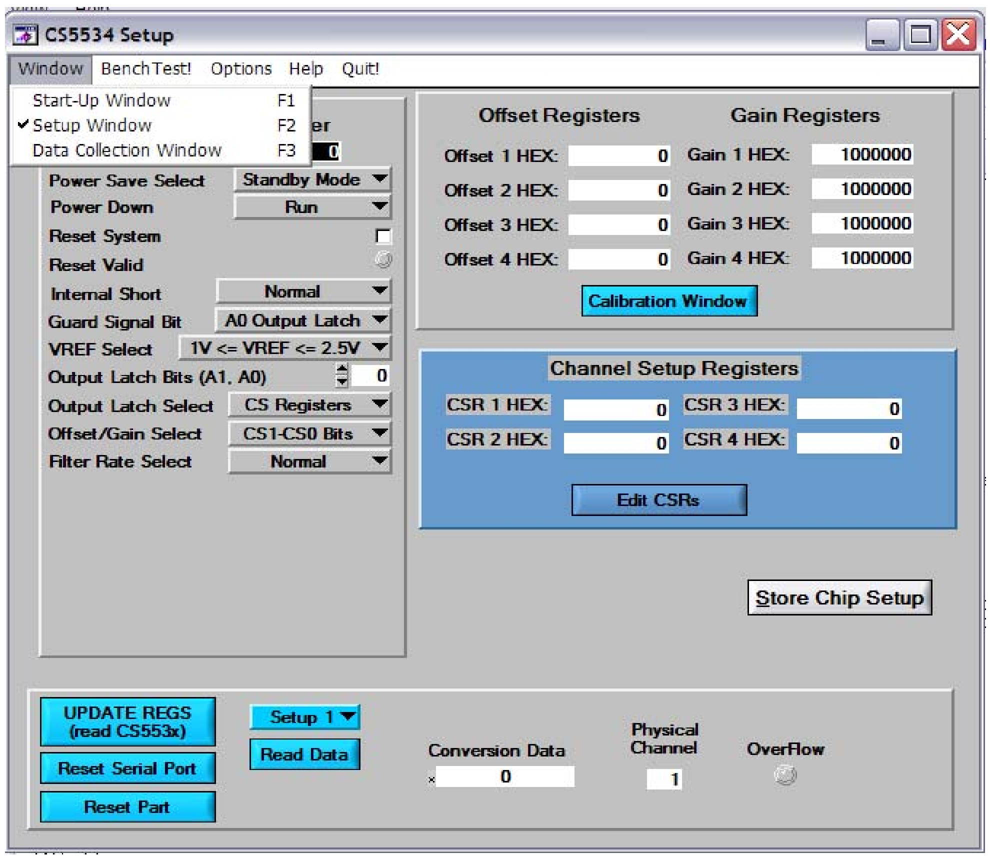
GUI Version: 3.0

Firmware Version: 3.0

Copyright 2006 Cirrus Logic Inc.

FIGURE 73 VERSION IDENTIFICATIONS

This panel reads the version of the firmware running on the microcontroller. The panel title in the upper left corner is the name of the chip being evaluated.



Power Save Select: Standby Mode
Power Down: Run
Reset System
Reset Valid
Internal Short: Normal
Guard Signal Bit: A0 Output Latch
VREF Select: 1V <= VREF <= 2.5V
Output Latch Bits (A1, A0): 0
Output Latch Select: CS Registers
Offset/Gain Select: CS1-CS0 Bits
Filter Rate Select: Normal

Offset Registers		Gain Registers	
Offset 1 HEX:	0	Gain 1 HEX:	1000000
Offset 2 HEX:	0	Gain 2 HEX:	1000000
Offset 3 HEX:	0	Gain 3 HEX:	1000000
Offset 4 HEX:	0	Gain 4 HEX:	1000000

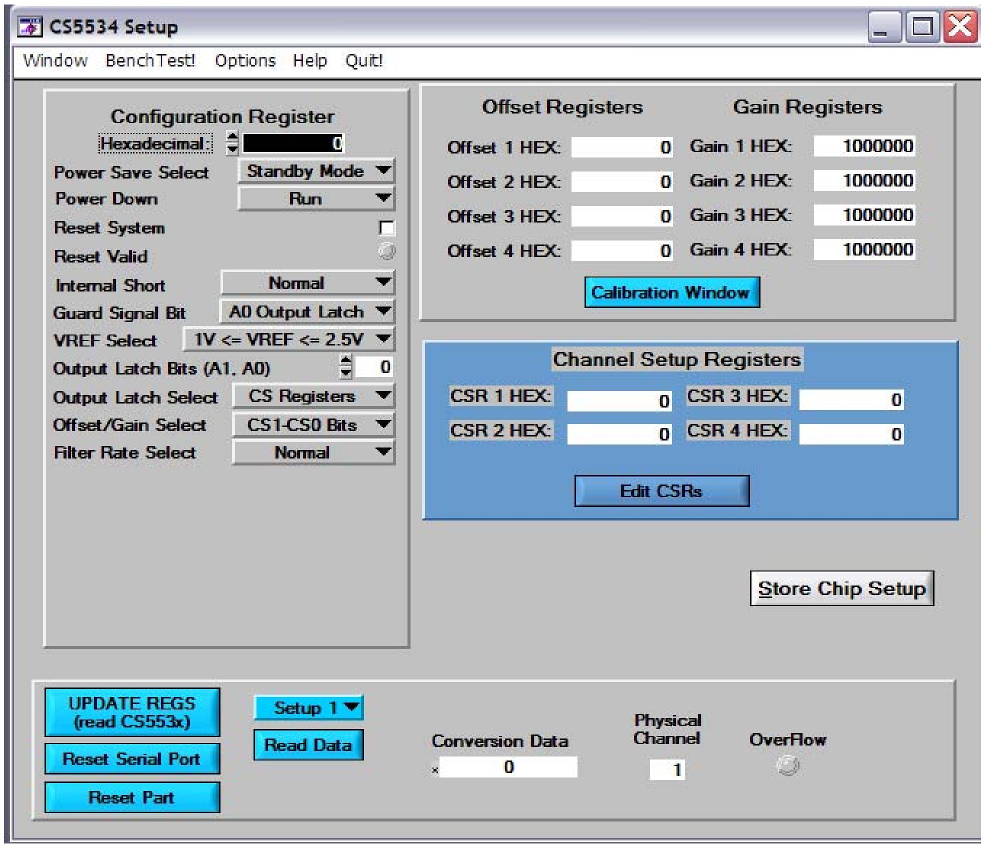
Channel Setup Registers

CSR 1 HEX:	0	CSR 3 HEX:	0
CSR 2 HEX:	0	CSR 4 HEX:	0

Conversion Data: 0
Physical Channel: 1
OverFlow

FIGURE 74 MENU DRIVEN

I designed this application to be menu driven. This shows the selection of panels that can be accessed from the menu. There is a panel that is not shown because what is displayed is the customer version. I will not display the engineer version because it is only used in-house. It was a requirement that the same code be used for the engineering and customer versions which would make the application easier to maintain. I used compiler directives “Engineering” and “Customer” to achieve this task.



Configuration Register

Hexadecimal	0
Power Save Select	Standby Mode
Power Down	Run
Reset System	
Reset Valid	
Internal Short	Normal
Guard Signal Bit	A0 Output Latch
VREF Select	1V <= VREF <= 2.5V
Output Latch Bits (A1, A0)	0
Output Latch Select	CS Registers
Offset/Gain Select	CS1-CS0 Bits
Filter Rate Select	Normal

Offset Registers		Gain Registers	
Offset 1 HEX:	0	Gain 1 HEX:	1000000
Offset 2 HEX:	0	Gain 2 HEX:	1000000
Offset 3 HEX:	0	Gain 3 HEX:	1000000
Offset 4 HEX:	0	Gain 4 HEX:	1000000

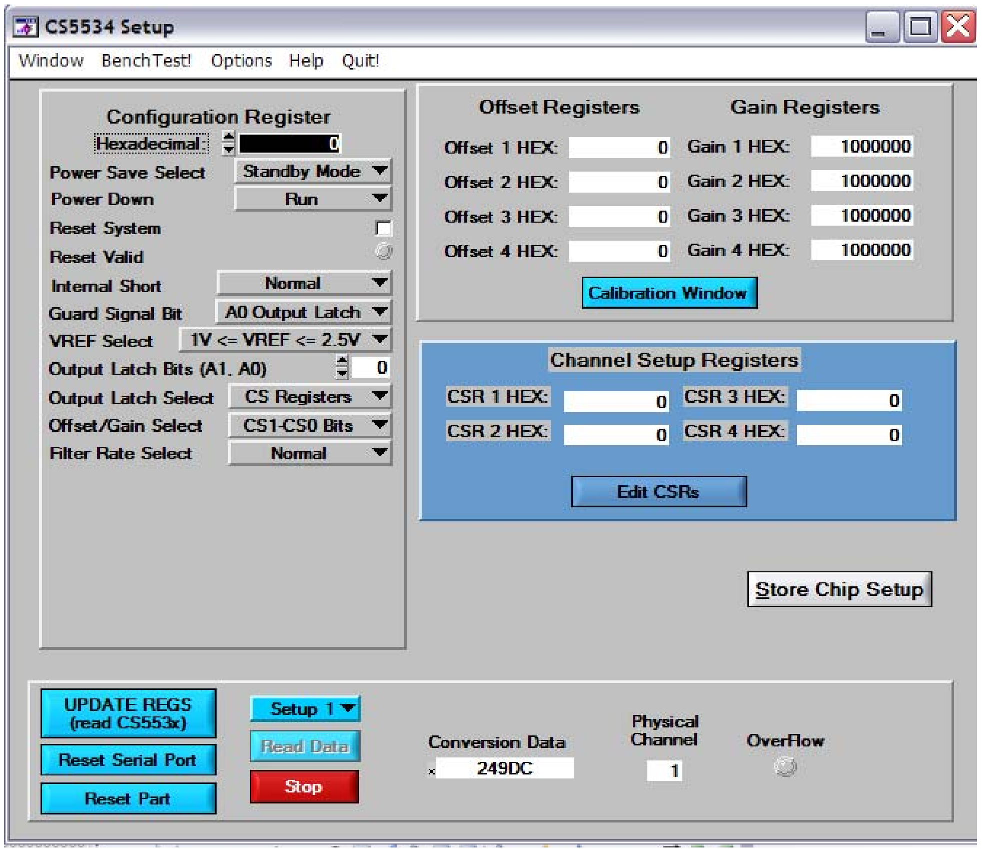
Channel Setup Registers

CSR 1 HEX:	0	CSR 3 HEX:	0
CSR 2 HEX:	0	CSR 4 HEX:	0

Setup 1	
Conversion Data	0
Physical Channel	1
OverFlow	

FIGURE 75 SETUP PANEL

From the “Setup Panel”, the ADC registers can be configured. This chip contains four types of registers: configuration, offset, gain, and channel setup. These physical objects, internal to the chip, represent structures in the actual code. In the configuration group, drop down boxes contain different items that can be selected. When a selection occurs, the event “Event-Commit” is generated. The callback function associated with the control and the event is executed. In this case, four bytes containing changes to the configuration register are written across the USB port to the chip.   Pressing the “Reset Serial Port” sends fourteen 0xFF and one 0xFE to the microcontroller. This allows the microcontroller to synchronize the universal serial bus.   Pressing the “Rest Part” button sends a reset chip command. This resets the chip and sets the reset valid flag.   Pressing “ Update Regs” runs the call back function that reads the registers on the chip. The configuration register must be read after every valid reset before a command can be executed. I have written a read-back function within every callback for validated the command has been completed and decoding it to update the control.


CS5534 Setup

Window BenchTest! Options Help Quit!

Configuration Register

Hexadecimal:	0
Power Save Select	Standby Mode
Power Down	Run
Reset System	☐
Reset Valid	○
Internal Short	Normal
Guard Signal Bit	A0 Output Latch
VREF Select	1V <= VREF <= 2.5V
Output Latch Bits (A1, A0)	0
Output Latch Select	CS Registers
Offset/Gain Select	CS1-CS0 Bits
Filter Rate Select	Normal

Offset Registers / Gain Registers

Offset 1 HEX:	0	Gain 1 HEX:	1000000
Offset 2 HEX:	0	Gain 2 HEX:	1000000
Offset 3 HEX:	0	Gain 3 HEX:	1000000
Offset 4 HEX:	0	Gain 4 HEX:	1000000

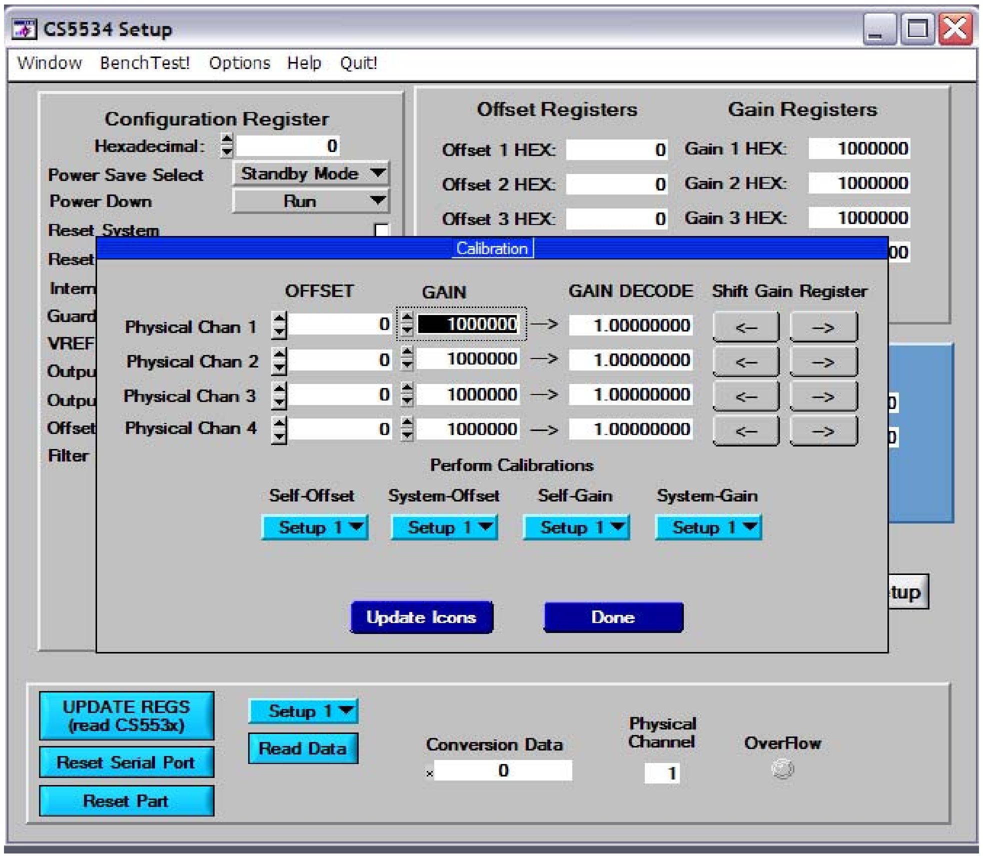
Channel Setup Registers

CSR 1 HEX:	0	CSR 3 HEX:	0
CSR 2 HEX:	0	CSR 4 HEX:	0

Conversion Data	Physical Channel	OverFlow
249DC	1	○

FIGURE 76 SINGLE CONVERSION MODE USING SOFTWARE TIMER

Pressing the “Read Data” button places the chip in single conversion mode. The frequency of the conversion command is sent to the chip based on a software timer. The indicator title “Conversion Data” is the converted data from the ADC. In this case, “Setup 1” is used. This is the channel setup used for the conversion.



Configuration Register

Hexadecimal: 0

Power Save Select: Standby Mode

Power Down: Run

Offset Registers		Gain Registers	
Offset 1 HEX:	0	Gain 1 HEX:	1000000
Offset 2 HEX:	0	Gain 2 HEX:	1000000
Offset 3 HEX:	0	Gain 3 HEX:	1000000

	OFFSET	GAIN	GAIN DECODE	Shift Gain Register	
Physical Chan 1	0	1000000	1.00000000	<-	->
Physical Chan 2	0	1000000	1.00000000	<-	->
Physical Chan 3	0	1000000	1.00000000	<-	->
Physical Chan 4	0	1000000	1.00000000	<-	->

Self-Offset: Setup 1

System-Offset: Setup 1

Self-Gain: Setup 1

System-Gain: Setup 1

Setup 1

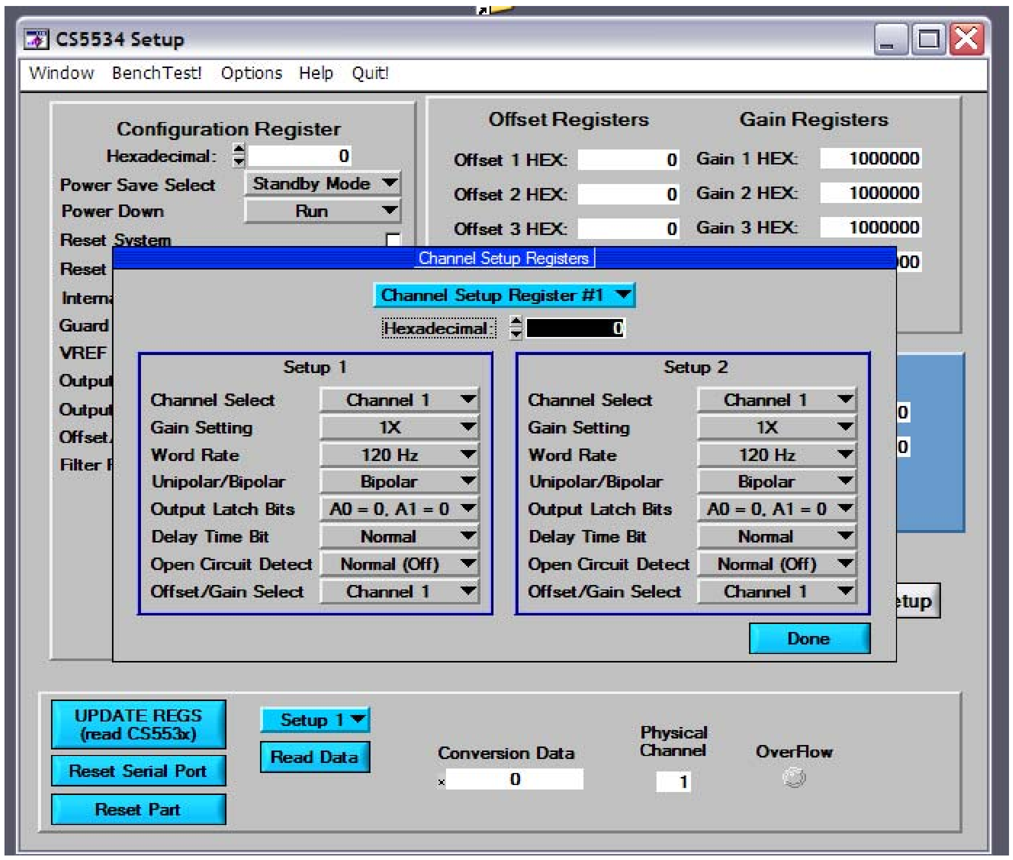
Conversion Data: 0

Physical Channel: 1

OverFlow

FIGURE 77 CALIBRATION

Pressing the “Calibration Window” button and the above panel pop ups. From this panel, the chip and the system can be calibrated. Self-offset determines the zero offset for the chip. System offset is when external voltage is applied to the system. This is similar for Gain. Pressing the “Done” button exits the panel.



Configuration Register
Hexadecimal: 0
Power Save Select: Standby Mode
Power Down: Run
Reset System

Offset Registers		Gain Registers	
Offset 1 HEX:	0	Gain 1 HEX:	1000000
Offset 2 HEX:	0	Gain 2 HEX:	1000000
Offset 3 HEX:	0	Gain 3 HEX:	1000000

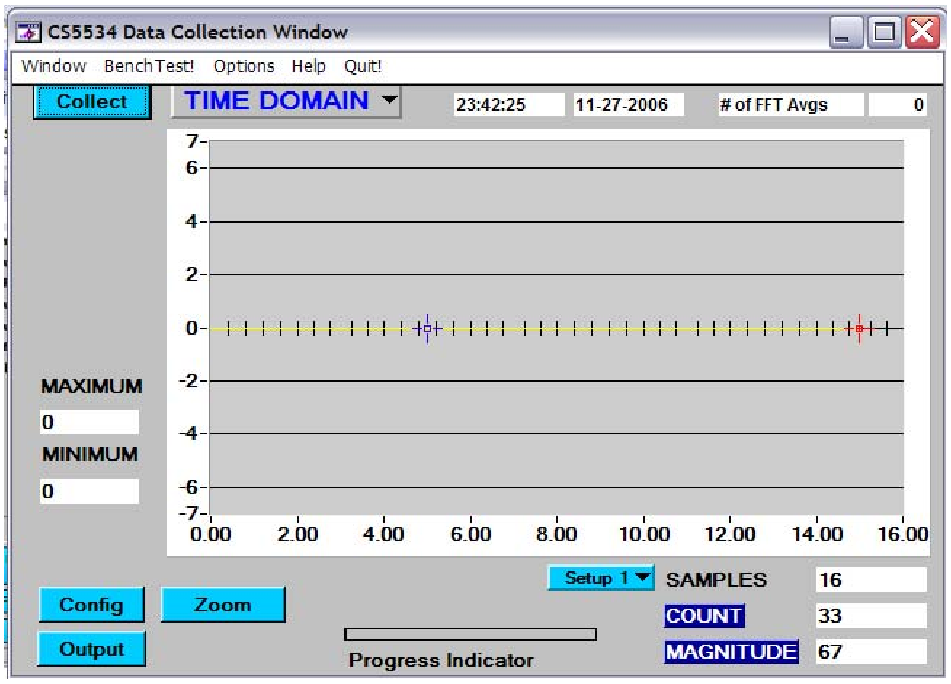
Channel Setup Register #1
Hexadecimal: 0

	Setup 1		Setup 2
Channel Select	Channel 1	Channel Select	Channel 1
Gain Setting	1X	Gain Setting	1X
Word Rate	120 Hz	Word Rate	120 Hz
Unipolar/Bipolar	Bipolar	Unipolar/Bipolar	Bipolar
Output Latch Bits	A0 = 0, A1 = 0	Output Latch Bits	A0 = 0, A1 = 0
Delay Time Bit	Normal	Delay Time Bit	Normal
Open Circuit Detect	Normal (Off)	Open Circuit Detect	Normal (Off)
Offset/Gain Select	Channel 1	Offset/Gain Select	Channel 1

Setup 1
Conversion Data: 0
Physical Channel: 1

FIGURE 78 CHANNEL SETUP PANEL

From this panel, the channel setup register can be configured. The channel setup register is a 32 bit register configured in 16 bit size. The number of internal registers depends on the chip. Also, the CS5530 chip has no channel setup register.



23:42:25

11-27-2006

# of FFT Avgs: 0

MAXIMUM: 0

MINIMUM: 0

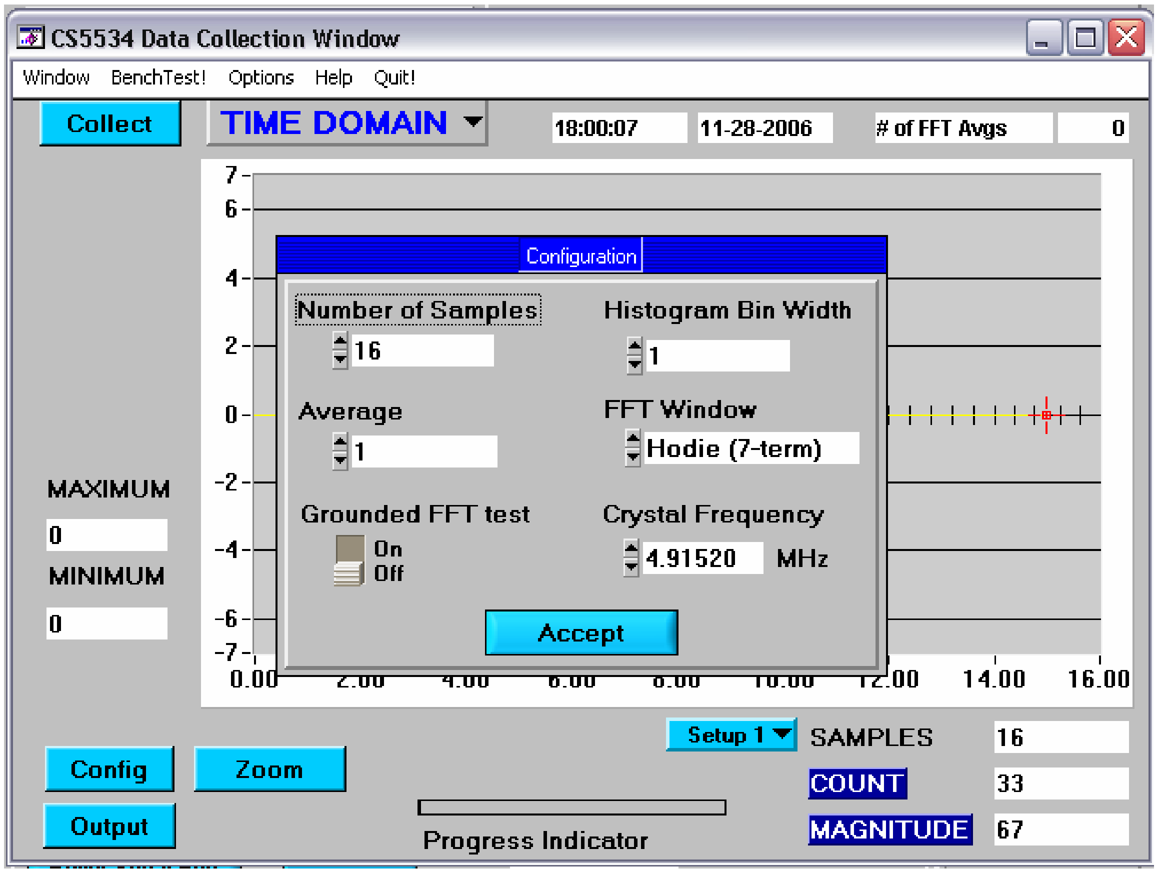
SAMPLES: 16

COUNT: 33

MAGNITUDE: 67

FIGURE 79 DATA COLLECTION WINDOW (ANALYSIS)

The panel above will be presented when selecting from the “Data Collection Window” menu. Pressing the “Collect” button places the ADC in continuous conversion mode and starts the collection process of the conversion. The drop-down box determines how to plot the data in the time or frequency domain, and the histogram. The data from the ADC is stored in an array. The same data can be plotted in all three selections. The date time and the average number is also displayed. Averaging is used to reduce the noise floor which improves the signal-to-noise ratio. This concept was discussed in detail in the “Analysis” section above. The “Progress Indicator” shows the progress of the execution. It indicates that the application is running and not halted for any reason. The “# of FFT Avgs” shows the average number being plotted. The “Setup 1” determines which channels set up register to use during conversions. When the “Config” button is pressed the “Configuration” panel displays.


CS5534 Data Collection Window
Window BenchTest! Options Help Quit!
Collect
TIME DOMAIN
Config
Zoom
Output
Setup 1
Accept
Progress Indicator

18:00:07 11-28-2006 # of FFT Avgs 0

MAXIMUM 0
MINIMUM 0

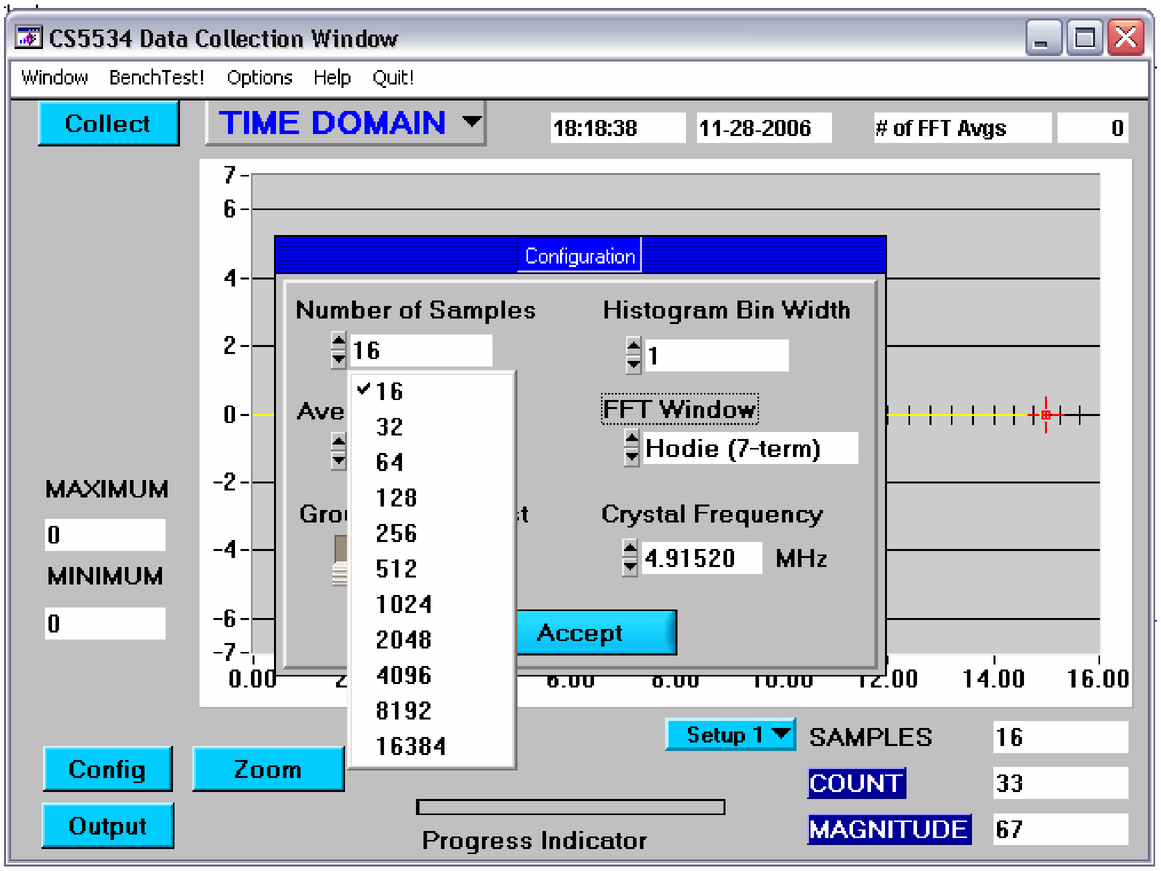
Configuration

Number of Samples 16
Histogram Bin Width 1
Average 1
FFT Window Hodie (7-term)
Grounded FFT test On Off
Crystal Frequency 4.91520 MHz

SAMPLES 16
COUNT 33
MAGNITUDE 67

FIGURE 80 CONFIGURATION PANEL (# SAMPLES, AVERAGE, FFT WINDOW, HISTOGRAM WIDTHS)

From this panel, the number of samples, the histogram bin width, how many averages, and the windowing function can be selected. These numbers can be indexed in or selected from a drop down menu like the one shown below.



18:18:38 11-28-2006 # of FFT Avgs 0

Number of Samples 16

16, 32, 64, 128, 256, 512, 1024, 2048, 4096, 8192, 16384

Histogram Bin Width 1

FFT Window Hodie (7-term)

Crystal Frequency 4.91520 MHz

MAXIMUM 0

MINIMUM 0

SAMPLES 16

COUNT 33

MAGNITUDE 67

FIGURE 81 CONFIGURATION SAMPLE NUMBER DROP DOWN LIST

The following figures show the different plots available and the analysis values.

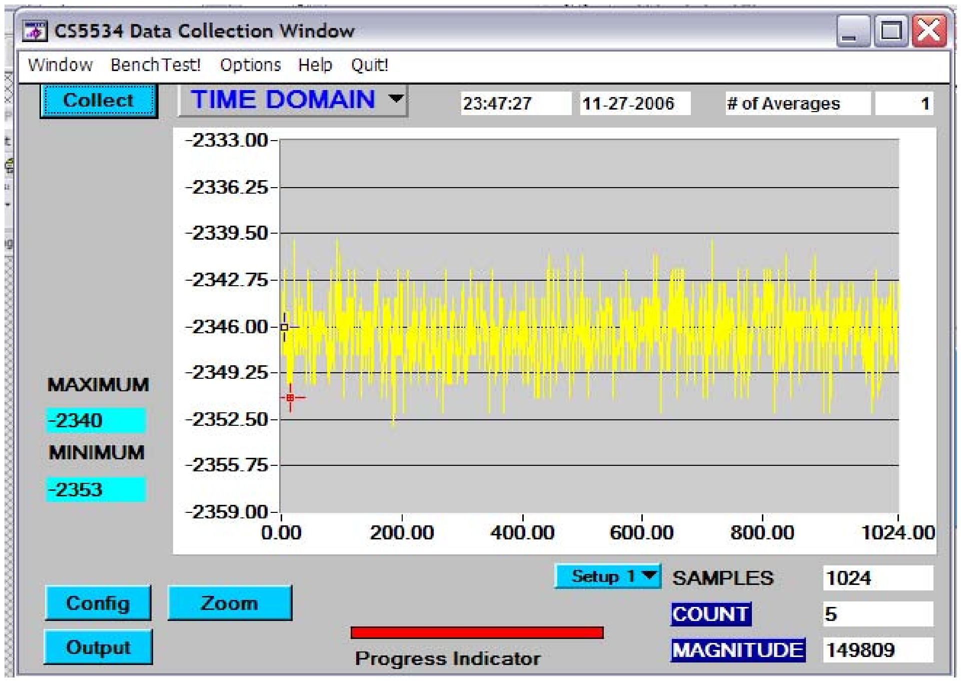
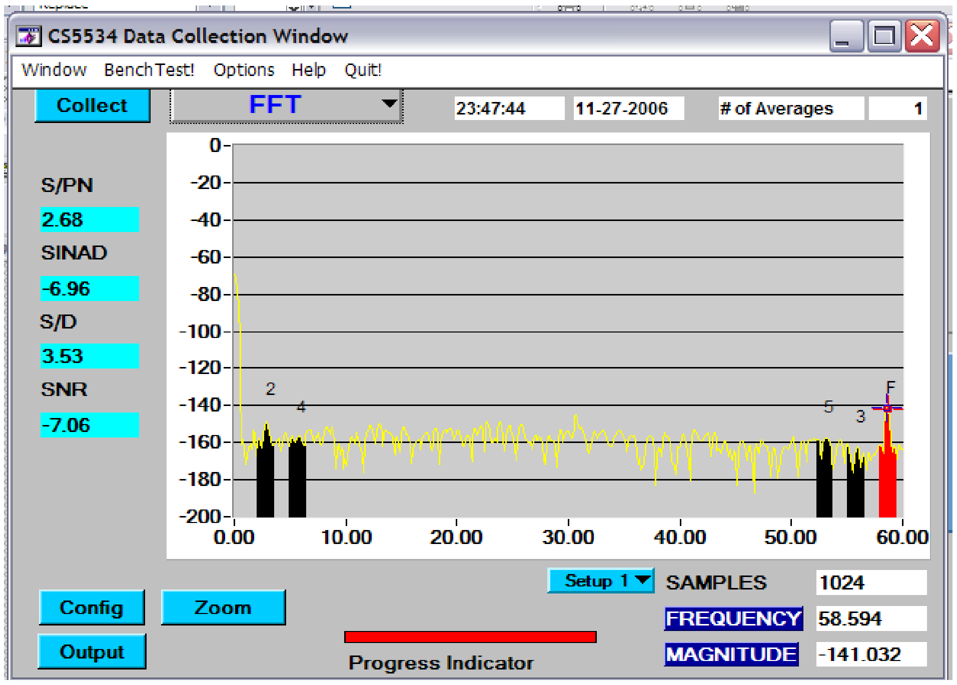


FIGURE 82 TIME DOMAIN 1024 SAMPLES

The y-axis displays the converted codes from the ADC. The x-axis is the sample number. The analog input voltage values for this plot is zero the offset value. Zero is represented between -2340 and -2353, only a 13 code difference, (or noise), out of possible a 16.7 millions codes ($2^{24\text{ bits}}$). Selecting “FFT” from the dropped down box will do a Fast Fourier Transform on the collected data. The figure below demonstrates this concept.



23:47:44 11-27-2006 # of Averages 1

S/PN 2.68
SINAD -6.96
S/D 3.53
SNR -7.06

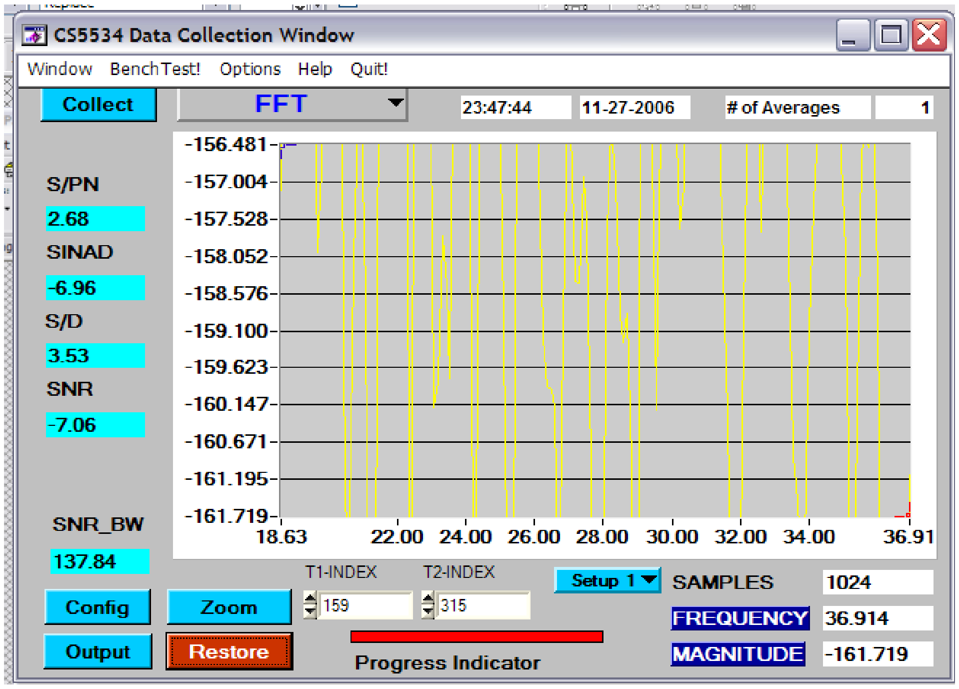
SAMPLES 1024
FREQUENCY 58.594
MAGNITUDE -141.032

FIGURE 83 FFT OF CONVERTED DATA

The y-axis is in decibel values of the conversions. The x-axis is the frequencies up to the Nyquist range which is half of the maximum input frequency. The numeric indicator title "Frequency" shows the frequency value that a crosshair is positioned on. The magnitude is the y-axis decibel value. These values are updated as the crosshairs are repositioned on the plot. The following output are calculated and shown:

S/PN	- signal to peak noise
SINAD	- signal to noise plus distortion
S/D	- signal to distortion
SNR	- signal to noise ratio

I have defined and explained how to calculate these values in the "Analysis" section above. Zoom is a feature that was requested by a design engineer. The engineer wanted to be able to expand a segment of the plot. There are two crosshairs. The Blue Crosshair must be positioned before the Red Cross hair. The user presses "Zoom" button. The graph is zoomed between the crosshairs. Also, I display the array index value that the crosshairs are positioned on. If the blue crosshair comes after the red crosshair an error message box pops up.



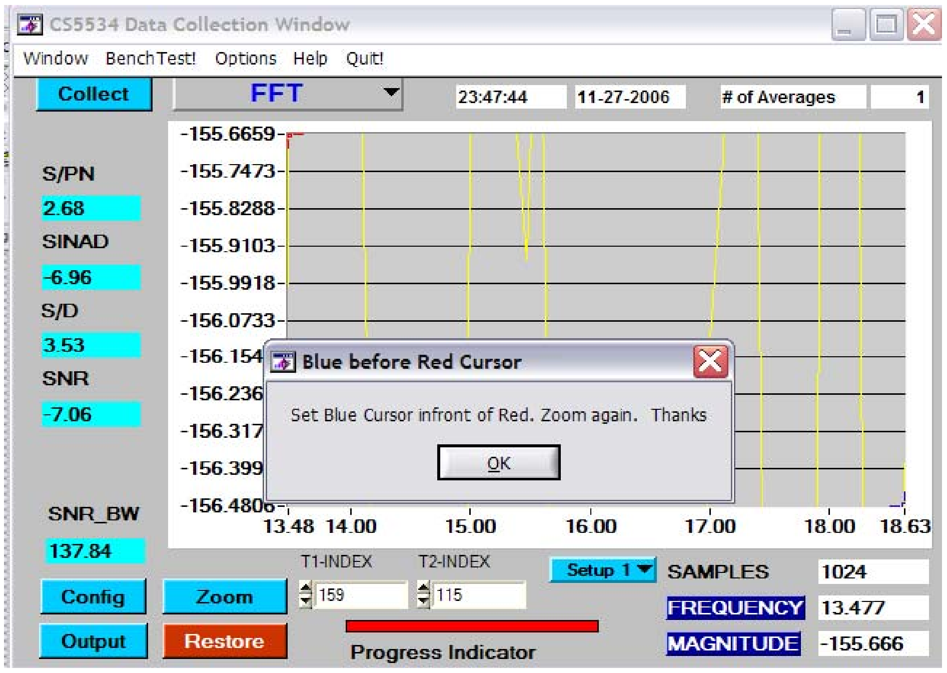
23:47:44 11-27-2006 # of Averages 1

S/PN 2.68
SINAD -6.96
S/D 3.53
SNR -7.06
SNR_BW 137.84

T1-INDEX 159
T2-INDEX 315

SAMPLES 1024
FREQUENCY 36.914
MAGNITUDE -161.719

FIGURE 84 ZOOM SEGMENT OF THE PLOT



23:47:44 11-27-2006 # of Averages 1

S/PN 2.68
SINAD -6.96
S/D 3.53
SNR -7.06
SNR_BW 137.84

T1-INDEX 159
T2-INDEX 115

SAMPLES 1024
FREQUENCY 13.477
MAGNITUDE -155.666

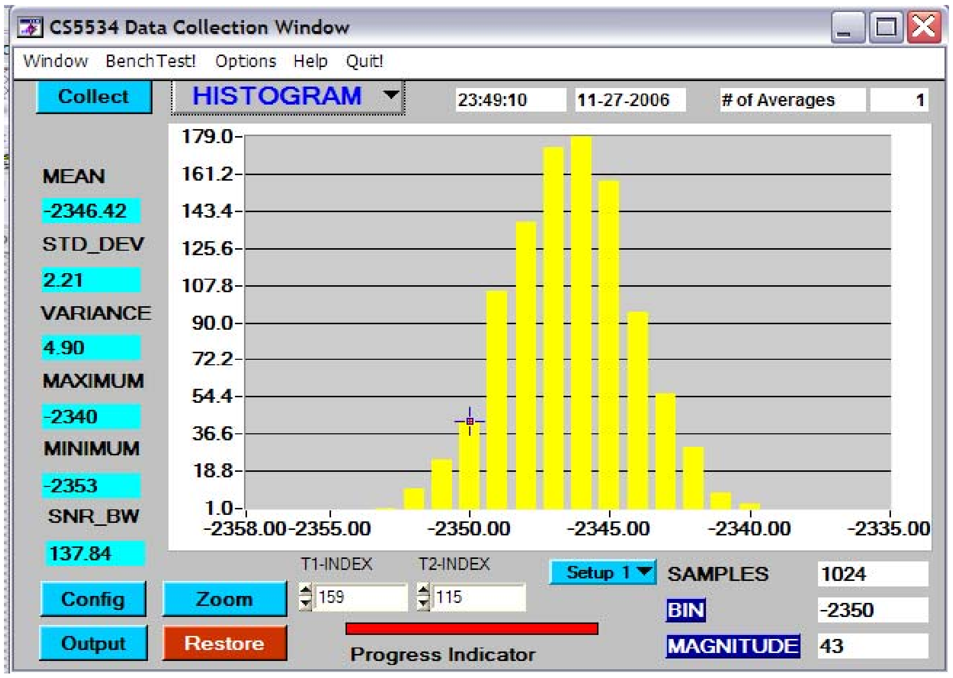
Blue before Red Cursor

Set Blue Cursor infront of Red. Zoom again. Thanks

OK

FIGURE 85 ERROR MESSAGE WHEN CURSORS ARE OUT OF ORDER

The next figure is a plot of the histogram. The histogram shows the frequency of codes collected. The y-axis is the number of codes collected and the x-axis is the actual code itself.



23:49:10 11-27-2006 # of Averages 1

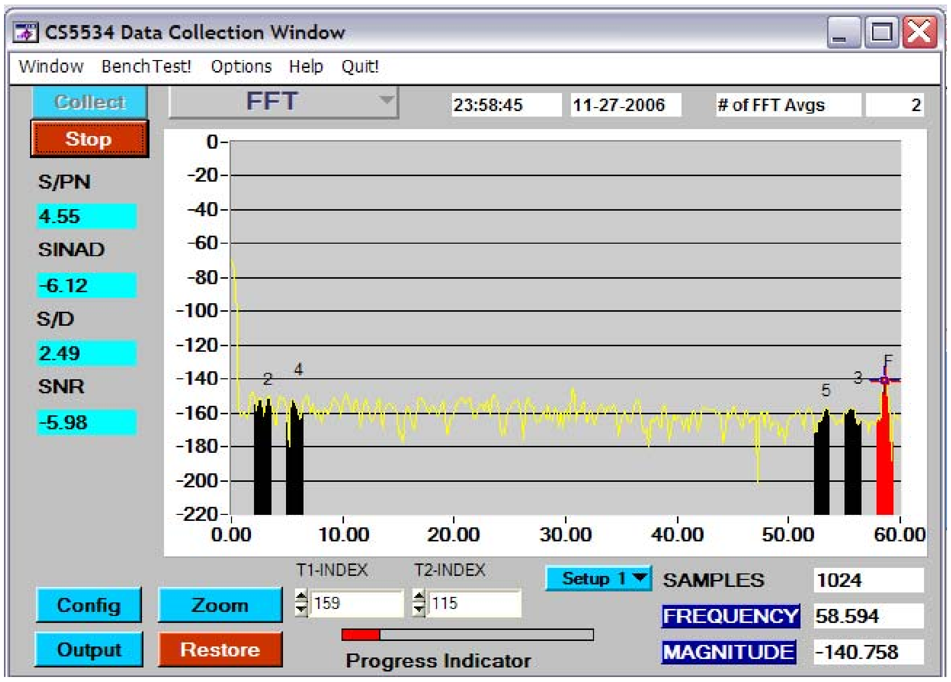
MEAN -2346.42
STD_DEV 2.21
VARIANCE 4.90
MAXIMUM -2340
MINIMUM -2353
SNR_BW 137.84

T1-INDEX 159 T2-INDEX 115

SAMPLES 1024
BIN -2350
MAGNITUDE 43

FIGURE 86 HISTOGRAM OF ZERO VOLT INPUT

As an example, the number of -2345.00 code collected is 179. This histogram is a nice Guassian curve that would be expected from random noise in the system. The following figures show the effect of averaging on the floor noise. The numeric indicator “# of FFT Avgs” displays which average is being plotted.



23:58:45
11-27-2006
# of FFT Avgs 2

S/PN 4.55
SINAD -6.12
S/D 2.49
SNR -5.98

T1-INDEX 159
T2-INDEX 115

SAMPLES 1024
FREQUENCY 58.594
MAGNITUDE -140.758

FIGURE 87 AVERAGE PLOTTED 2

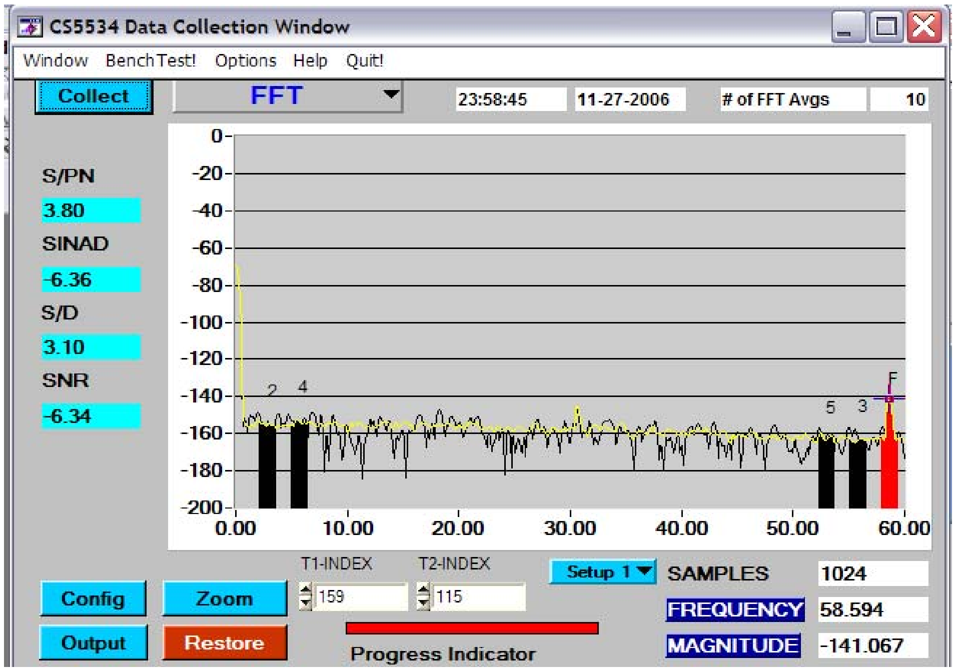
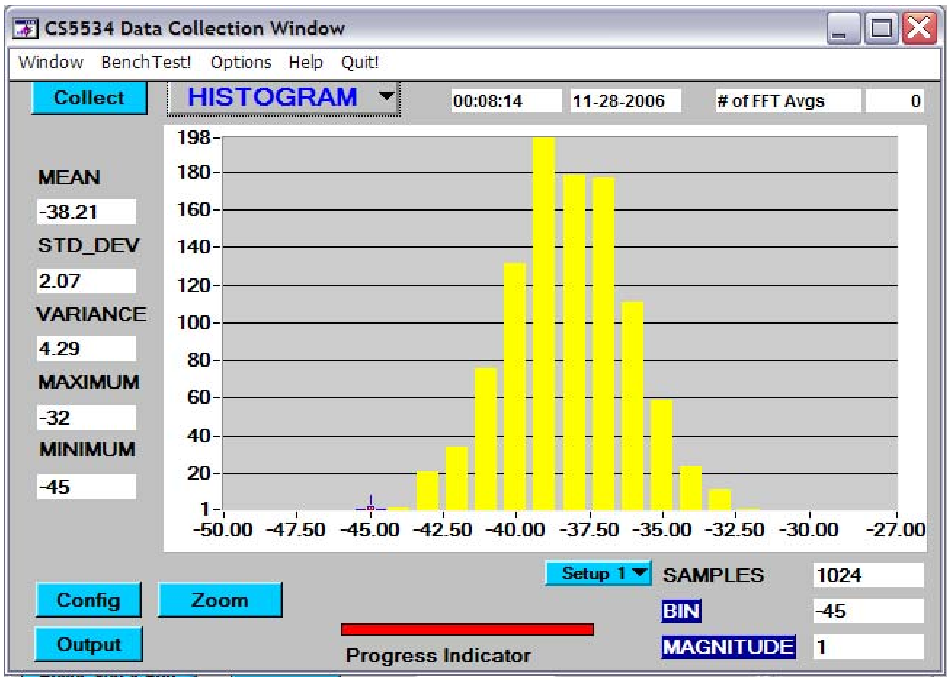


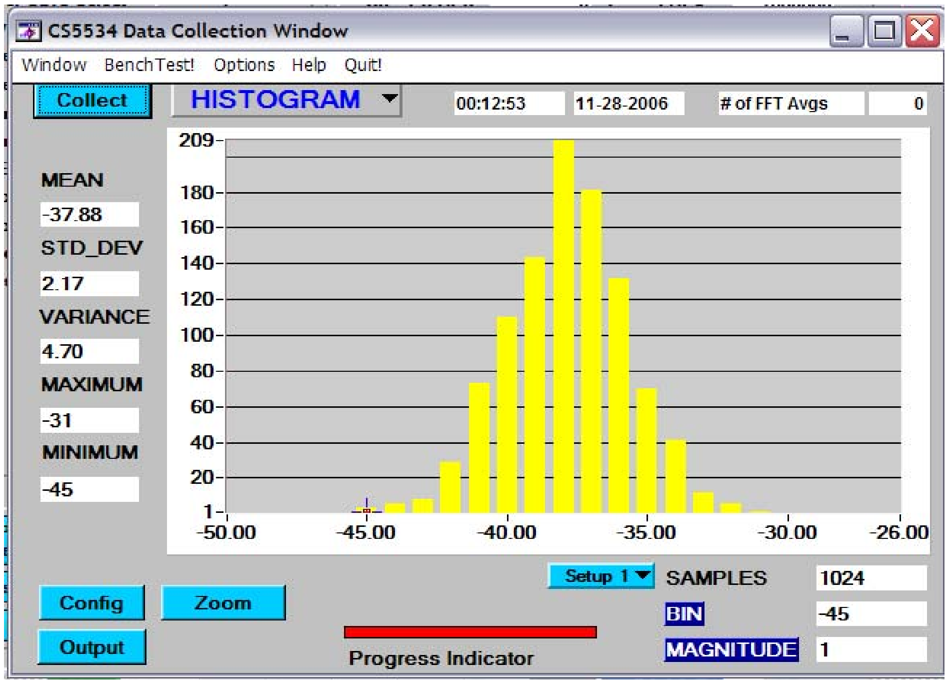
FIGURE 88 AVERAGE PLOTTED 10

“Average Plotted 2” has a higher noise floor the “Average Plotted 10” that is represented by the black line. The peak label “F” is the fundamental. Peaks label “2”, “3”, “4”, and “5” are the second, third, fourth, and fifth harmonics. The next two figures show how the bell-shape curve is affected by offset and gain calibration. The first histogram plot is without calibration and the second plot is with calibration.



MEAN -38.21
STD_DEV 2.07
VARIANCE 4.29
MAXIMUM -32
MINIMUM -45
SAMPLES 1024
BIN -45
MAGNITUDE 1

FIGURE 89 NO CALIBRATION



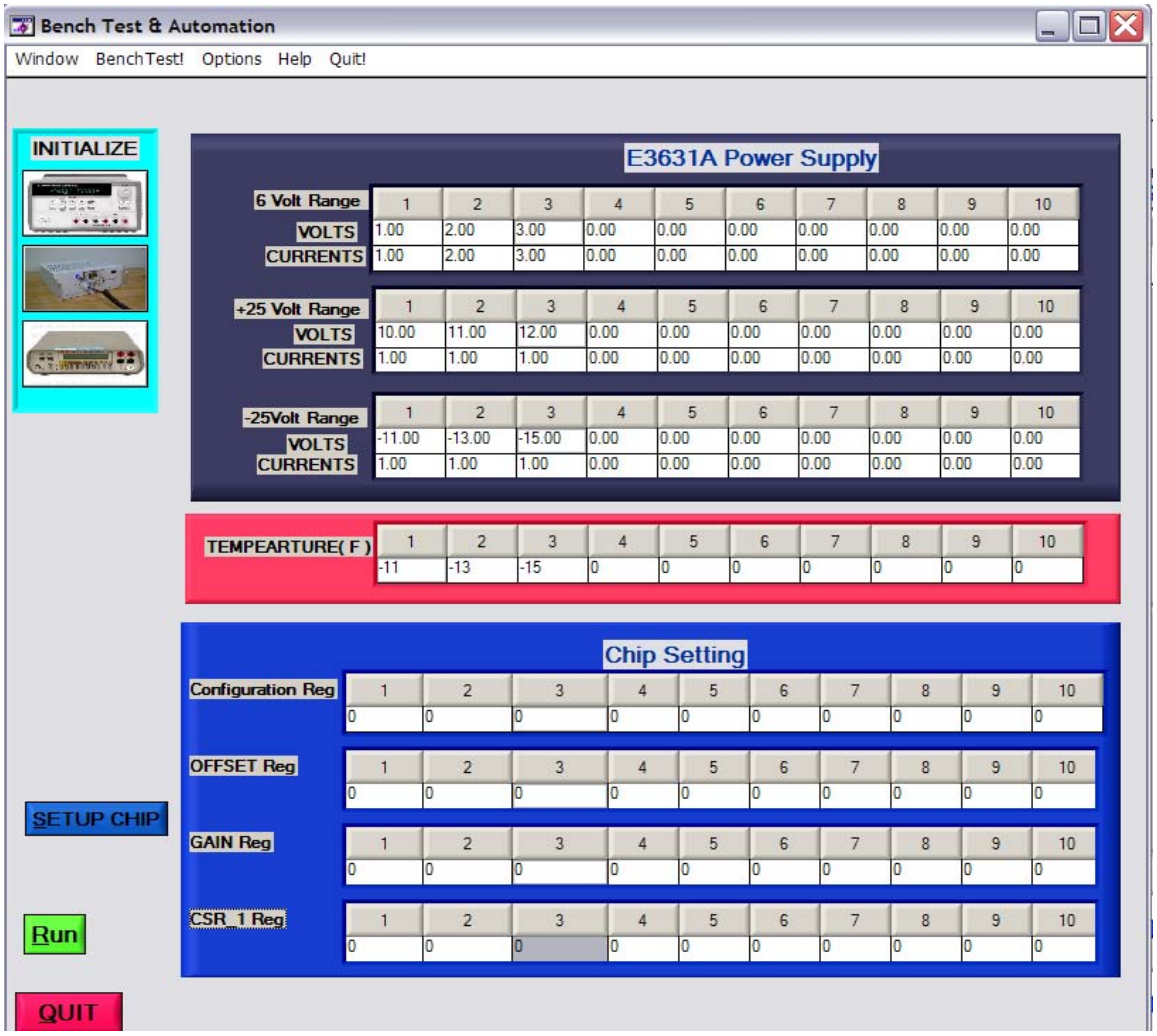
00:12:53 11-28-2006 # of FFT Avgs 0

MEAN -37.88
STD_DEV 2.17
VARIANCE 4.70
MAXIMUM -31
MINIMUM -45

SAMPLES 1024
BIN -45
MAGNITUDE 1

FIGURE 90 WITH OFFSET AND GAIN CALIBRATIONS

To set up the tri-state HP3631A power supply, the Silicon Thermal, and Keithley multimeter “BenchTest!” is selected from the menu. The following panel is displayed when this is completed.



E3631A Power Supply

6 Volt Range	1	2	3	4	5	6	7	8	9	10
VOLTS	1.00	2.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CURRENTS	1.00	2.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

+25 Volt Range	1	2	3	4	5	6	7	8	9	10
VOLTS	10.00	11.00	12.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CURRENTS	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

-25Volt Range	1	2	3	4	5	6	7	8	9	10
VOLTS	-11.00	-13.00	-15.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CURRENTS	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TEMPEARTURE(F)	1	2	3	4	5	6	7	8	9	10
	-11	-13	-15	0	0	0	0	0	0	0

Chip Setting

Configuration Reg	1	2	3	4	5	6	7	8	9	10
	0	0	0	0	0	0	0	0	0	0

OFFSET Reg	1	2	3	4	5	6	7	8	9	10
	0	0	0	0	0	0	0	0	0	0

GAIN Reg	1	2	3	4	5	6	7	8	9	10
	0	0	0	0	0	0	0	0	0	0

CSR_1 Reg	1	2	3	4	5	6	7	8	9	10
	0	0	0	0	0	0	0	0	0	0

FIGURE 91 AUTOMATION PANEL

The panel is broken into four groups: Initialize, Power Supply, Temperature and Chip Setting. Up to ten different values can be set for latter three groups. The initialize group is used to setup and establish the communication protocol to the test instruments. The initialize group has three buttons. Each button has an image of the test instrument on it that it represents. When a button is pressed a panel pop-ups that will allow the initialization of the instrument and a method to check to make sure communication is established. For the power supply and temperature group to change a cell value, the cell simply needs to be selected and then the new value entered. The constraints are handled through the control properties. For example, a 6 volt range of the power supply cannot have a value greater then 10 volts and source current greater then 5 amps. The control will not allow a voltage value greater then 6 volts and a current value greater than 5 amps. The power supply data structure is:

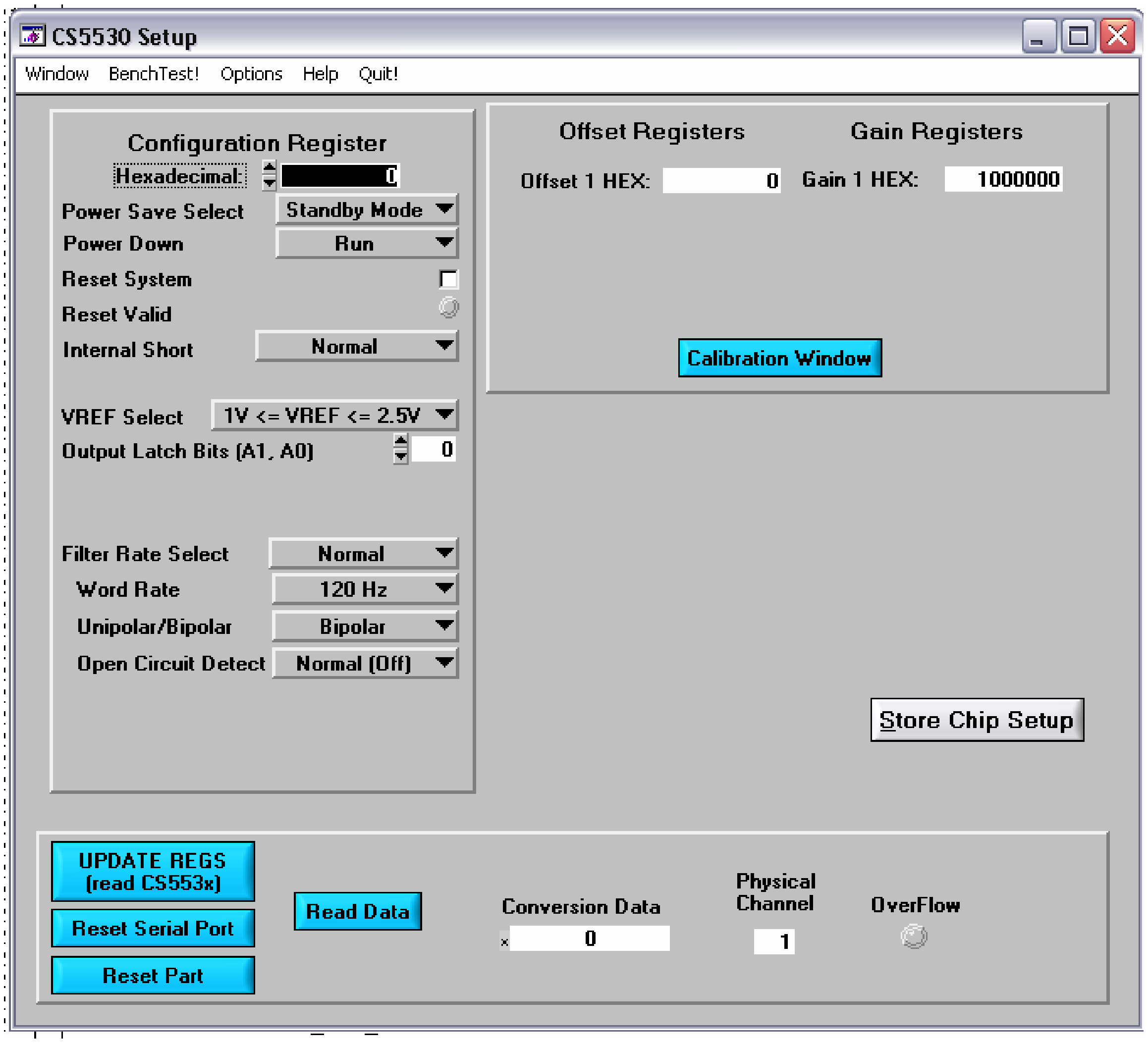
```
struct{
        int ps6V,
        int ps6A,
        int ps25V,
        int ps25A,
        int psm25V,
        int psm25A,
        int size
        } PS;
```

The temperature and power control behave similarly. The temperature data structure is just an array of size ten. The chip data structure is more complex. When the “Setup Chip” button is pressed the chip setup panel is displayed to the front. All the register settings are just hexadecimal numbers.

For example, the configuration register setting is composed of four, two digit hexadecimal numbers. For the configuration and channel setup register, the user selects the setting from the controls drop down box and a hexadecimal number is generated. The calibration values are populated automatically when the selected calibration is done. When the "Storage" button is pressed the hexadecimal values populate their corresponding control values on the "Automation" panel. The constraints are up to ten setting and channel setup registers, one must be use for conversions. The data structure for chip setting is:

```
struct{
        int config_reg;
        int offset_reg;
        int gain_reg;
        int csr1_reg;
        }DUT;
```

The CS5530 chip is the exception. The CS5530 chip does not contain a channel setup register. The configuration register determines the "Word Rate" and which channel to convert. When the CS5530 chip is selected, the channel setup register is dimmed out. The following figures show the "Setup" and "Data Collection" windows for this chip. Notice there is no channel setup register and only one offset and gain register appears. The application interface appearance is a function of the chip being selected because of the differences in the internal structure of the chips within the CS55xx family.


CS5530 Setup

Window BenchTest! Options Help Quit!

Configuration Register

Hexadecimal: 0

Power Save Select: Standby Mode

Power Down: Run

Reset System

Reset Valid

Internal Short: Normal

VREF Select: 1V <= VREF <= 2.5V

Output Latch Bits (A1, A0): 0

Filter Rate Select: Normal

Word Rate: 120 Hz

Unipolar/Bipolar: Bipolar

Open Circuit Detect: Normal (Off)

Offset Registers

Offset 1 HEX: 0

Gain Registers

Gain 1 HEX: 1000000

Calibration Window

Store Chip Setup

UPDATE REGS (read CS553x)

Reset Serial Port

Reset Part

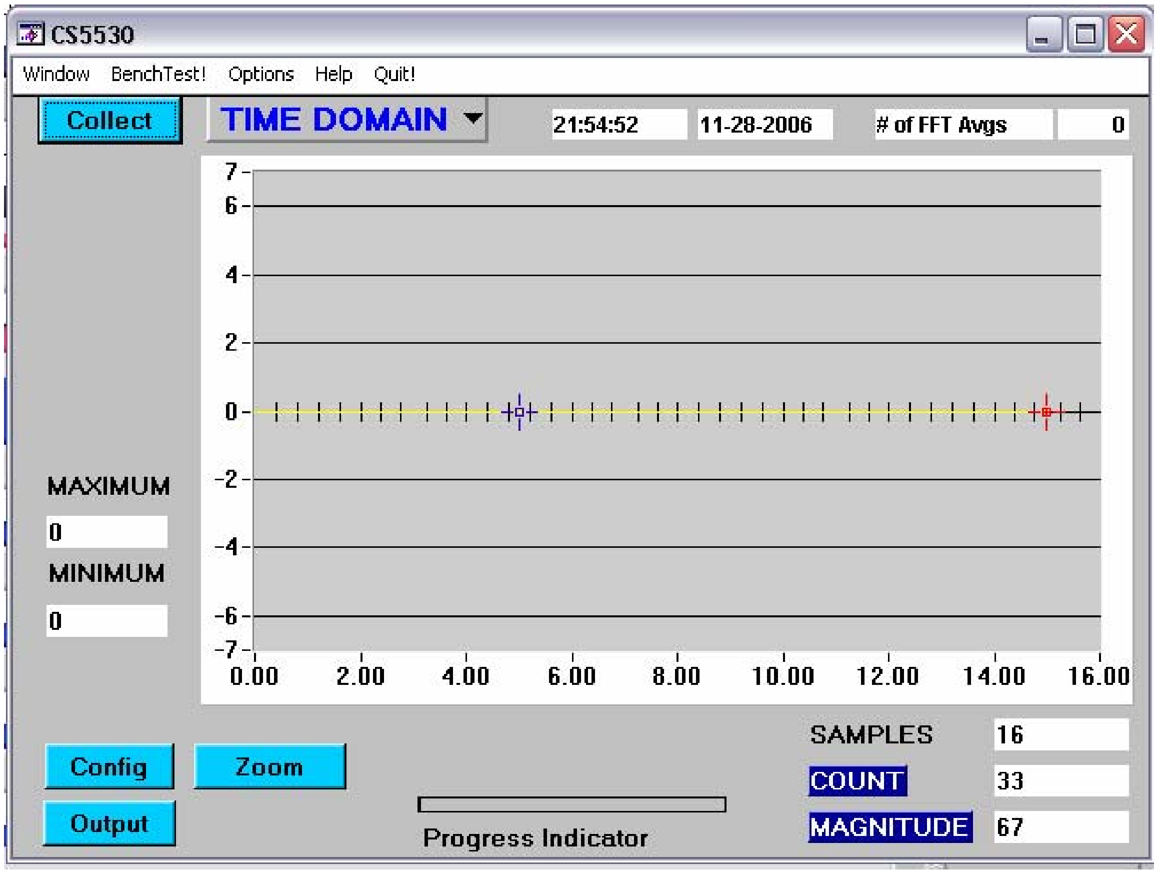
Read Data

Conversion Data: 0

Physical Channel: 1

OverFlow

FIGURE 92 CS5530 SETUP PANEL



21:54:52 11-28-2006

# of FFT Avgs 0

MAXIMUM 0

MINIMUM 0

SAMPLES 16

COUNT 33

MAGNITUDE 67

FIGURE 93 CS5530 DATA COLLECT PANEL

CHAPTER 6

CONCLUSION

In this thesis, I have presented company C.L. with a testing environment. I have designed the environment so that it would be independent of the chip being characterized. The environment application is modular so that it can be reused. It follows the philosophy that software is the test instrument. I also developed the application to control the family of CS553x ADC and the microcontroller code. In addition, I presented a methodology of architecting future applications with Unified Modeling Language. I have also suggested to the manager that the chip register bits structure should be the common for all future chips. In other words, the reset bit would be same bit number for all chips designed by the industrial group. This would make future application development easier and faster.

BIBLIOGRAPHY

[1] NI (1996-2003), “LabWindows/CVI Basics I Course Manual”, Austin, TX.

[2] NI (1996-2003), “LabWindows/CVI Basics II Course Manual”, Austin, TX.

[3] NI, “LabWindows CVI/8.1”, Retrieved from http://www.ni.com/lwcvi

[4-6] NI (1995-2003), “Data Acquisition and Signal Conditioning Course Manual”, Austin, TX. pp. 1-17.

[4] McClellan, James H., Schafer, Ronald W. and Yoder, Mark A. (1998) DSP First A Multimedia Approach, Prentice Hall, 1998.

[7] Cooley, J. W., Lewis, P. A. , and Welch, P. D., “Historical Notes on the Fast Fourier Transform,” IEEE Trans. Audio Electroacoustics, Vol. AU-15, pp 76-79, June 1967.

[8-9] NI (1995-2003), “Data Acquisition and Signal Conditioning Course Manual”, Austin, TX. pp. 2.13-2.17.

[8] McClellan, James H., Schafer, Ronald W. and Yoder, Mark A. (1998) DSP First A Multimedia Approach, Prentice Hall, pp. 359-361, 1998.

[8] NI, “The Fundamental of FFT-Based Signal Analysis and Measurement in LabView and LabWindows/CVI”, Retrieved: http://zone.ni.com/devzone/cda/tut/p/ide/4278.

[10-15] Crystal, “Introduction to Analog-to-Digital Converters”,(1991).

[10,16] NI (1995-2003), “Data Acquisition and Signal Conditioning Course Manual”, Austin, TX. pp. 2.13-2.59.

[17] McClellan, James H., Schafer, Ronald W. and Yoder, Mark A. (1998) DSP First A Multimedia Approach, Prentice Hall, pp. 89-93, 1998.

[17] NI, "The Fundamental of FFT-Based Signal Analysis and Measurement in LabView and LabWindows/CVI", Retrieved: http://zone.ni.com/devzone/cda/tut/p/ide/4278.

[18] Oppenheim, Alan V., Schafer, Ronald W., and Buck, John R., (1989) Discrete-Time Signal Processing 2nd, Prentice Hall, pp 144-150.

[19-20] Crystal, "Introduction to Analog-to-Digital Converters",(1991).

[21-22] Kalbfleisch, J. G., Probability and Statistical Inference 2nd, Springer-Verlag, pp. 16, 201-202.

[23-29] Crystal, "Introduction to Analog-to-Digital Converters", (1991).

[23-29] Hayes, Monson H., McGraw-Hill, Theory and Problems of Digital Signal Processing, (1999).

[30] McCarthy, Mary, Analog Devices, Application Notes 611, (2003).

[31] Crystal, "Introduction to Analog-to-Digital Converters", (1991).

[31-32] Crystal, "Frequency Domain Analysis", AN147 (1999).

[33-35] Harris, J. F., "On the Use of Windows for Harmonic Analysis with the Discrete Fourier Transform.", Journal of the IEEE, Vol. 66, No.1, Jan 1978.

[36-42] Crystal, "Frequency Domain Analysis", AN147 (1999).

[43] Blaha, Michael and Rumbaugh, James, Prentice Hall, Object-Oriented Modeling and Design with UML 2nd, (2005).

[44-46] Cirrus Logic, "CS5530 24-bit ADCs with Ultra-low-noise PGIA", (2006).

[47-54] Cirrus Logic, "CS5531/32/33/34 24-bit ADCs with Ultra-low-noise PGIA", (2005).

[55-57] Axelson, Jan, USB Complete, Lakeview Research, WI. 1999.

[58-62] Silicon Laboratories, “C8051F320/1 Full Speed USB, 16k ISP Flash MCU Family”, (2003).

[63] Blaha, Michael and Rumbaugh, James, Prentice Hall, Object-Oriented Modeling and Design with UML 2nd, (2005).

[63] Booch Grady, Jacobson Ivar and Rumbaugh, James, Addison-Wesley, UML Distilled Applying the Standard Object Modeling Language, (1997).

[64-65] NI, “LabWindows CVI/8.1”, Retrieved from http://www.ni.com/lwcvi.

[66-67] Bascom-AVR Manual, “Using the SPI protocol” , Retrieved from http://avrhelp.mcselec.com/bascom-avr.html?Using_the_SPI_protocol, (1995-2006).

[68-71] Travis, Jeffrey and Wells, Lisa K., LabView For Everyone Graphical Programming Made Even Easier, Prentice Hall, (1997).

[68-69] GPIB User Manual for Win32, NI, (1998).

[70-71] RS485 Data Interface, ARC Electronics, Retrieved from http://www.arcelect.com/RS485_info_Tutorial.htm

VITA

Robert C. Murphy was born in a small town in North Carolina on June 28, 1964. After completing his work at Greene Central High School in Greene County in 1983, he entered North Carolina State University in Raleigh. He received the degree of Bachelor of Science from North Carolina State University in Electrical and Computer Engineering. He later attended University of Texas at Austin where he received the degree of Master of Science in Engineering and the degree of Doctor of Philosophy in the discipline of Solid State Engineering. He has been employed at various companies in his pursuit of knowledge like Texas Instrument, Bell Northern Research, National Renewable Energy Laboratory, Cirrus Logic and more. In 2004, he entered the Graduate College of Texas State University-San Marcos.

Permanent Address: 7201 S. Congress Avenue #537

Austin, Texas 78745

This thesis was typed by Robert C. Murphy.