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Comparison of conventional DAQ systems and embedded DAQ systems

by

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DECLARATION

The work contained in this thesis is original except acknowledged in the customary manner, and has not been submitted previously for a degree at any University. To the best of my knowledge and belief this thesis contains no material previously published or written by another person, except where due reference is made.

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ABSTRACT

In this research we compare conventional data acquisition system (DAS) with the embedded data acquisition systems. The performance specifications of 4 different types of DAQ cards are drawn up with special emphasis made on the following parameters: Slew rate, settling time, relative accuracy and system noise. These parameters are taken from 2 conventional DAS and then compared to those taken from 2 embedded data acquisition systems under the same electrical conditions. The embedded DAQ system's hardware was built using the PIC Microcontroller interfaced to the Digital to Analog Convertors (DAC). MPLAB C18 is used to create a program which communicates with the embedded DAQ system, to transmit generated signals. National Instrument's LabView is used to create a program which communicates with the conventional DAQ system, to acquire external generated signals and retransmit the signals. In most cases the performance of conventional and embedded are close, but one of the embedded DAS seem to be unstable at high frequencies.

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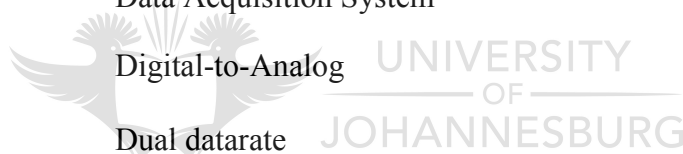
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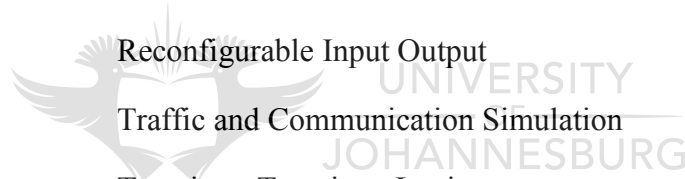
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ABBREVIATIONS AND ACRONYMS

ABBREVIATION	MEANING
ADC	Analog-to-digital converter
A/D	Analog-to-Digital
BMS	Bluetooth Media Access Control Scanner
CAN	Controller Area Network
CPU	Central Processing Unit
CRT	Cathode Ray Tube
DAC	Digital-to-Analog Converter
DAQ	Data Acquisition
DAS	Data Acquisition System
D/A	Digital-to-Analog
DDR	Dual datarate
ECG	Electrocardiography
EEG	Electroencephalogram
EtherCAT	Ethernet for Control Automation Technology
FPGA	Field-Programmable Gate Array
GPIB	General Purpose Interface Bus
I/O	Input Output
IMAQ	Image Acquisition
INL	Integral Non-Linearity
IVI	Interchangeable Virtual Instruments
kS/s	Kilo Samples Per Second
LabVIEW	Laboratory Virtual Instrument Engineering Workbench Environment



LSB	Least significant bit
Mac	Macintosh
MAX	Measurement & Automation Explorer
MCU	Microcontroller Unit
MPLAB IDE	MPLAB Integrated Development
MS/s	Mega Samples Per Second
NI	National Instruments
OS	Operating System
PC	Personal Computer
PCB	Printed Circuit Board
PCI	Peripheral Component Interconnect
RAM	Random Access Memory
RIO	Reconfigurable Input Output
TCS	Traffic and Communication Simulation
TTL	Transistor-Transistor Logic
USB	Universal Serial Bus
VDD	Voltage Drain Drain
VI	Virtual Instrument
VISA	Virtual Instrument Standard Architecture



Chapter 1

Introduction

1.1 Introduction

In this chapter the background, rational for this research, problem statement, objectives, scope of the study, limitations of the study, methodology, limitation of the methods, unique contribution of the research and the overview of the thesis are discussed.

1.2 Background and Rationale for research

Conventional data acquisition systems have been used with transducers mainly to collect changing data parameters resulting from conditions such as temperature and pressure (National Instruments, 2012a). When any of these two mentioned conditions are applied to a transducer input, the transducer detects the mentioned conditions and turns them into small voltage or current variations. Data acquisition (DAQ) systems collect these resulting signals onto the computer for storage and analysis. In the past, research to employ conventional DAQ systems in Electronics measurement tools were conducted (Kularatna, 1996). This led to digital oscilloscopes, signal generators, curve tracers and spectrum analyzers. Without these devices nowadays it is very difficult to perform duties in the electronics field. This research was motivated by the great demand for digital type of measurement electronics tools. Conventional DAQ cards (DAQ cards that can be obtained off shelves) may be used to create tools to measure electronic signals, however they come at high cost and demand advanced programs to program them. We must also remember that the processing speed of microcontrollers has increased drastically over the past few years, therefore high speed microcontrollers can now be used to create high speed embedded DAQ systems. In this research conventional DAQ systems are compared to the embedded DAQ systems to determine whether their performances are closely related or not.

1.3 Problem statement

Simple ways to compare and study the performance the Data Acquisition System (DAS) are not documented; it is therefore difficult for one to choose a DAQ system that is required for any unique demand. It is also difficult to test and document the performance specifications of any DAS. Ultimately there are no simple methods to verify the specification of any given DAQ card.

Unlike DAQ systems, standalone electronics measuring instruments possess one specific function, for example the digital oscilloscope can only collect values representing voltage changes over a time domain (Electronic specifier, 2012). When these instruments are used to conduct Electrical Engineering experiments, several challenges arise:

- More than one kind of measuring instrument is required to complete at least one experiment.
- The cost becomes high, since individual tools will have to be purchased (Pico Technology, 2000).
- Adding to the large number of individual instruments, equipment sharing is also difficult.
- Conventional DAQ cards can be used to acquire multiple signals; however they are more expensive and require sophisticated programs for their use.

Only advanced programs such as National Instrument (NI)'s Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) are used with traditional conventional DAQ systems to create and deploy measurement as well as control systems (National Instruments, 2012b).

1.4 Objectives of the study

The main aim of this project is to compare conventional DAQ systems with embedded DAQ systems and the secondary objectives are to:

- model simple methods for comparing and testing DAQ systems.
- document performance specifications based on slew rate, settling time, relative accuracy and system noise for the four types of used DAQ cards.
- reveal whether modern microcontrollers can be successfully utilised to create best performing embedded DAS or not.
- create MPLABC and LabVIEW code that can be used when evaluating DAQ systems.

1.5 Scope of the study

In this research simple methods to compare various DAQ cards will be developed. These methods will also be used when testing performances of DAS and also to confirm some of their performance specifications. The methods are verified by comparing two embedded DAQ systems with two conventional DAQ systems. The embedded DAQ systems performance will be evaluated and compared to that of conventional DAQ systems. NI myDAQ and NI myRIO-1900 will be used for comparison with the embedded DAQ systems. For further information on these two conventional DAQ systems, refer to their respective datasheets (National Instruments, 2013a) and (National Instruments, 2013b).

1.6 Limitations of the study

In this research we focus on the performances of DAS at frequencies not higher than 30 kHz and voltages not higher than 20 V peak to peak. The following are not covered:

- Design and construction of printed circuit boards (PCB's) due to higher costs.
- Test of signals above 30 kHz and or above 20 V peak to peak; these signals are rarely used as baseband frequencies
- The design for the interfacing circuit between the computer and an embedded DAQ system. These are obtained with development boards.

1.7 An overview of the methodology and design

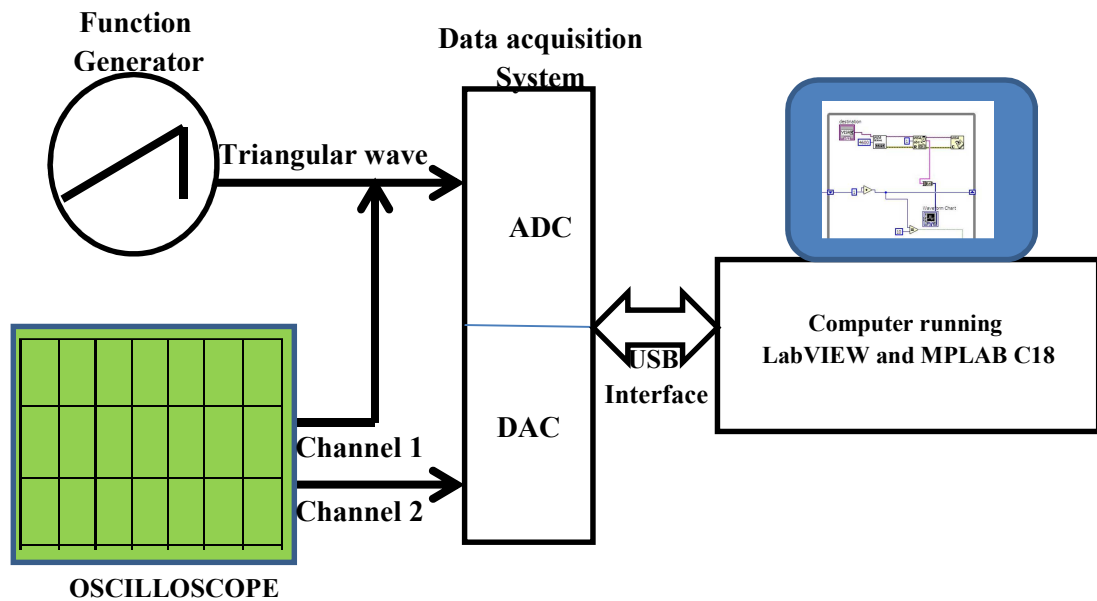


Figure 1a: Test equipment and connections for data acquisition systems

In this experimental research the performance specifications of 4 different types of DAQ systems are drawn up with special emphasis made on the following parameters: slew rate, settling time, relative accuracy and system noise. These parameters are taken from the 2 conventional DAQ Systems and then compared to those taken from 2 embedded DAQ systems under the same electrical conditions. The embedded DAQ system's hardware was built using the PIC Microcontroller interfaced to the Digital to Analog Convertors (DAC). MPLAB C18 is used to create a program for the selected microcontroller. DAC circuits were built on Vero boards and then interfaced with the microcontrollers to form an embedded DAQ system. National Instrument's LabVIEW is used to create a program which communicates with the purchased off shelf conventional DAQ systems, this program acquire external generated signals and retransmit the signals. In most cases the performance of conventional and embedded are close, but one of the embedded DAS seem to be unstable at high frequencies.

Please refer to the block diagram titled Figure 1a above. The function generator supplies the linear waveform to the conventional DAQ system through the analog input where an Oscilloscope's channel 1 is conected. LabVIEW program acquires this input signal and then pass it to the DAS analog output where the oscilloscope's channel 2 is connected.

The embedded DAS is interfaced with the host computer via serial to USB circuit (Nickel, 2010). This computer hosts MPLAB C18 to:

- exchange data with the embedded DAS (Deitel, 2010),
- create and deploy a test programming code.

When comparing the conventional and embedded DAQ systems, the following performance specifications are considered: **1) System noise** comes from external sources such as the AC power lines, motors, generators, transformers, fluorescent lights, soldering irons, Cathode Ray Tube (CRT) displays, computers, lightning, welders, radio transmitters, and internal sources such as semiconductors, resistors, and capacitors. **2) Relative Accuracy** is a measure in Least Significant Bits (LSBs) of the worst-case deviation from the ideal transfer function called best fit line. **3) Settling time** gives information about the time required by the converter to meet the right output value after a change in the input code. **4) Slew rate** is maximum rate of voltage change which the analog output channel is capable of. It is given by change in voltage over a given change in time.

1.8 Unique contribution

This research will establish simple techniques for evaluating and comparing conventional DAQ systems with embedded DAQ systems. This provides a model for testing DAQ system as well to verify performance parameters of a given DAQ system. The research also creates a foundation for the paper that will still be written with the title: “The use of microcontroller based embedded DAQ systems on electronic signals measurement”.

1.9 Overview of the thesis

In chapter 1, problem statement and the objectives, methodology and limitations of this experimental research are outlined. In chapter 2, literature that is related or similar to this one is discussed. Research procedures and methods are discussed in Chapter 3. In chapter 4, documented experiments results are presented. In chapter 5, short explanations, graphs and tables are used to compare conventional DAQ systems with embedded DAQ systems. The thesis is concluded on Chapter 6 by summarizing the observations and suggesting future research on DAQ cards.

Chapter 2

Literature review

2.1 Introduction

A Data Acquisition Card (DAQ card) is the device used to transfer data collected from sensors such as thermistors, photo cells, electronic circuits, etc. to a computer. The method helps on the transfer of input and output data, either in digital or analog form. DAQ cards operate by utilizing both DAQ hardware and software.

2.1.1 DAQ Hardware

DAQ hardware provides the physical interfacing between the analog or digital devices that will connect to the computer USB ports or in the form of PCI cards. PCI cards connect to slots in the motherboard, which then results onto higher transfer speeds when compared to their USB counterparts.

2.1.2 DAQ Software

Software is programmed onto DAQ cards to poll the DAQ input channels for any input changes and then samples the input signals at the configured data rate. In a similar fashion the software is used to transfer DAQ generated signals to the corresponding output channels.

- Drivers - facilitate communications between the DAQ Hardware and the operating system.
- Application software - enables a user configure data transfer rates and to process incoming or outgoing signals accordingly (e.g. LabVIEW)

2.1.3 Applications of DAS

When carefully selected, a DAQ card can be used to create a powerful and cost effective measurement tool. DAS is used to do the following basic measurements:

- Voltage
- Digital signals
- Frequency or time interval

The sensors that are used in DAS often return values in a form of voltage that can then be converted to the values of displacement, temperature, or whatever is being measured.

2.1.4 Manufactures of DAQ cards

- ADLINK Technology manufactures card such as ADLINK DAQ-2010 (ADLINK, 2012).
- Data Translation, Inc. manufactures DAQ cards such as DT2811.
- National Instrument, most popular. One example of their DAQ product is the NI USB-6008 (National Instruments, 2012a).

2.2 Data acquisition

Data acquisition (DAQ) is the measurement or generation of physical signals (Bishop, 2007). DAQ system consists of: Signals, Transducers, Signal-conditioning hardware, DAQ device or module and Application software.

2.2.1 Acquiring analog signals

Signals that vary continuously over a given time domain are referred to as analog signals, e.g. The temperature of water that is boiled in a kettle will rise gradually with time until the temperature reaches 100 °C.

To acquire this signal, firstly we will install a transducer (sensor) that will translate varying temperature on to varying voltage. After that we take samples from different time intervals. According to Nyquist rate, for each signal cycle there must be at least two equally spaced samples, in order to be able to reconstruct a meaningful signal. If it took you 30 second to boil the water, first sample will be taken after 15 seconds and the last one taken at 30 seconds. The process of taking samples is called quantization. The more samples you take the better your signal representation becomes.

After quantization each sample is translated to an equivalent digital value. The digits used on this representation are called bits and the process is called coding. If more bits are used the result will be better resolution (detail). Both quantization and coding are done by the Analog to Digital Convertors (ADC) that are controlled by the processor.

2.2.2 Acquiring digital signals

Digital Signals are non-continuous signals that only have two conditions, either HIGH or LOW. An example of this is the Electrocardiography (ECG) signal, it creates pulses with equal or varying periods. When digital signals are displayed over a time domain, the result is a square wave. To acquire this signal, firstly we will install a switch that is going to detect a condition. After that a processor collaborates with an A/D circuitry to do quantization and coding. In this case only two values will be obtained; hence output resolution is not a worrying factor.

2.2.3 Overview of LabVIEW as used for data acquisition

LabVIEW (short for Laboratory Virtual Instrument Engineering Workbench) is a graphical programming language that was designed with an aim for the users such as engineers and scientists to easily create advanced control, test and measurement applications. It is very user friendly programming software and therefore simplifies tasks for educators and learners (National Instruments, 2013c). It has more applications in instrument control, and industrial automation on a variety of operating systems including Microsoft Windows, various versions of UNIX, Linux, and Mac OS X. The latest version is LabVIEW 2014.

2.3 Conventional data acquisition

These are traditional techniques used to acquire data from external stimulus and /or traditional methods used to send out signals to external device. Data acquisition (DAQ) cards are used on instances where signals are collected or produced.

DAQ cards are made of multiple components (multiplexer, ADC, DAC, Transistor transistor logic input / output (TTL-IO), high speed timers, RAM. The space on the back of a PCI card might not be big enough to house all the connections needed, so an external breakout box is required (Leiden University, 2013). Components within DAQ card communicate with a processor of a microcontroller, which can run small programs. A controller offers more flexibility than a logic gates and is also cheaper than microprocessor so that it is permissible to block it with simple polling loops. For example: Waiting for an interrupt, starting and stopping of the digital to analog convertor (DAC), controlling built in timers, move value to volatile memories, switch multiplexer, get TTL input, etc.

Conventional DAQ cards will not function properly until the correct drivers have been installed. Once drivers have been installed, an application program will be able to control the activities done by the DAQ card.

National instruments LabVIEW support many utilities that can assist when Interfacing DAQ cards with the Personal computer:

2.3.1 **Measurement & Automation Explorer (MAX)** can be quickly used to test the functionality of a given conventional DAQ. It is an automated utility that provides quick access to the DAQ hardware which then results to easy and quick configurations (National Instruments, 2013d). With MAX, you can:

- Configure your National Instruments hardware and software
- Create and edit channels, tasks, interfaces, scales, and virtual instruments
- Execute system diagnostics and run test panels
- View devices and instruments connected to your system

2.3.2 **The DAQ Assistant** is a tool found in LabVIEW's block diagram screen. DAQ assistant can be used to create tasks for both input and output DAQ channels. Properties of this tool allow the user to configure the type of signals, data rates, levels, etc. DAQ Assistant also enables you to efficiently create a measurement channel or task for use in LabVIEW (National Instruments, 2013e). You also can use the DAQ Assistant to generate code for use in your applications.

The basic building block of a LabVIEW application is a virtual instrument (VI), which consists of a front panel and block diagram (National Instruments, 2013f).

Besides using the utilities mentioned earlier you can create a code from the beginning when using a Blank VI. The DAQ assistant is used within a Blank VI. There are also wizards you can use when you are creating a new code.

2.4 Embedded data acquisition

Embedded DAQ systems are characterized by the fact that the controlling software is programmed onto the DAQ module and resides within it. It is not necessary to permanently connect it to the host PC to make usage of peripherals such as bigger monitors, keyboards and mice. These are just stand alone devices that are highly portable (Unite Electronic Industries, 2013). In this study; embedded DAQ will be designed and then built using modern microcontrollers. MBLAB C18 is used to develop code that is required by these designed DAS.

2.4.1 The National Instruments CompactRIO is good example of the advanced embedded control and data acquisition system (National Instruments, 2013g). These devices consist of three major components i.e. the processor, Field programmable array (FPGA) and I/O slots fitted with different replaceable I/O cards e.g. cards that will support temperature readings. CompactRIO Application Areas are Aerospace/Avionics, Automotive, Energy/Power, Government/Defense, Industrial Controls/Devices/Systems, Machines/Mechanics, Medical Devices, Oil and Gas and Robotics.

2.4.2 myRIO is the National Instruments industry-standard reconfigurable I/O (RIO) technology, the enclosed version of NI myRIO (NI myRIO-1900) places 3 I/O connectors, Wi-Fi capabilities, a dual-core ARM real-time processor, and a customizable Xilinx FPGA. (National Instruments, 2013h). myRIO was aimed to improve student learning in various fields of electrical and electronics engineering

2.4.3 Microcontroller based data acquisition

Data acquisition circuits can also be designed and built to employ microcontrollers. This was demonstrated by the design of a general purpose microcontroller-based data acquisition device used for simple school experiments. The tool performs all tasks related to process measurement with focus on laboratory exercises (Dostalek, 2011). Performances of the microcontroller-based data acquisition are generally limited by the performance of analog-to-digital converter because they are

only capable of performing an accurate conversion if the analog input voltage is within the properly defined input range into the converter. Should the voltage range falls outside the acceptable limits; the conversion value will be inaccurate. The input range is set by the maximum and minimum values of references. In many instances the highest voltage level called V_{SS} is set to the supply voltage whilst the minimum voltage called V_{DD} is set to ground (0V). These define the voltage boundaries of the valid input range. Sometimes an external reference or references are used. In addition, some devices have built in voltage references that can be utilized. The sources for these voltage references can be configured by software when setting up the analog-to-digital converter in the PIC microcontroller (MCU). Note that there are restrictions on the voltage reference levels, for example: the reference voltages generally should not be lower than V_{SS} (source) or higher than V_{DD} (drain). There is also a minimum difference that is required between the high and low reference voltages (STMicroelectronics, 2013).

All the embedded data acquisitions that have been mentioned can interface with LabVIEW for data transfers and processing or programming. LabVIEW provides two programming models for CompactRIO systems. If one has LabVIEW Real-Time and LabVIEW FPGA on the development computer, one will have to select the programming model to use. (National Instruments, 2013i)

2.5 Factors that determine performance of DAQ cards

2.5.1 Analog outputs

Analog output circuitry is often required to provide stimuli for a DAQ system. Several specifications for the Digital-to-Analog Converter (DAC) determine the quality of the output signal produced (Physweb, 2013a). In sections 2.5.1 to 2.5.1.3 these specifications are discussed in detail.

2.5.1.1 Settling time

The duration by an operational amplifier or DAC output to settle to a specified accuracy is called the settling time. A higher settling time is a major problem because it results in inaccuracy that could vary with the gain and sampling rate (Colos University of Murcia, 2013).

2.5.1.2 Slew rate

The slew rate is the maximum rate of change that the DAC can produce on the output signal. Given by the change in voltage divided by the rising time. Fast DAS will have higher slew rate when compared to slow DAS. A DAC with a small settling time and a high slew rate can generate high-frequency signals because little time is needed to accurately change the output to a new voltage level (Physweb, 2013b).

2.5.1.3 Relative Accuracy/ Integral nonlinearity (INL)

This is a measure in LSBs of the worst-case deviation from the ideal DAQ board transfer function, a straight line called best fit line. Relative accuracy can be determined on an embedded DAQ by applying a linearly varying digital value to the input of a DAC, gradually increasing the values from minimum to maximum, and repeating the steps. Plotting the analog output will give a straight line that will not necessarily overlap with the best fit line. Subtracting actual straight-line values from the corresponding values of the best fit line gives the maximum deviation from zero and this is the relative accuracy of the DAQ board.

In the case of conventional DAQ a linearly varying signal is applied to the input channel of the DAQ. A DAS acquires the signal and retransmits it to one of its analog output channels where measurements are taken. Measuring procedure is similar to the one used for embedded DAS.

2.5.1.4 Noise

Unwanted signals that attach themselves to a digitized signal of the DAQ device are called noise. The personal computer is fitted with modules that generate higher noise levels; acquiring data on a plug-in device takes a careful layout on multiple-layer DAQ boards by designers (Paginas, 2013).

2.5.2 Analog Inputs

2.5.2.1 Sampling Rate

This parameter determines the number of points that are converted to digital values. The higher the sampling rate the greater the number of points acquired in a given time and this will form a better representation of the original signal. As an example, when music signals are converted to electrical signals by microphones. Commonly the frequencies will go up to 20 kHz. To properly digitize these signals for recording, the Nyquist sampling theorem states that the sampling frequency must be at least twice the highest possible input. So, a board with a sampling rate greater than 40 kS/s is needed to properly acquire this signal. This is just a minimum required rate which won't provide smooth signals.

2.5.2.2 Resolution

The number of bits used to form a digital code representing the value of each sampled signal point determines the precision of an ADC and is called resolution. The converted signal is a function of the number of bits the ADC uses to represent the digital data. The higher the resolution, the higher the number of divisions the voltage range is broken into, and therefore, the smaller the detectable voltages change. With an 8 bit ADC gives 256 levels (2^8) compared to a 12 bit ADC which will be giving 4096 levels (2^{12}). Therefore the 12 bit ADC will be able to detect smaller voltage changes of the input signals than an 8 bit ADC. LSB or least significant bit is defined as the minimum increment of the voltage that an ADC can convert.

A 3 bit ADC with the full scale of 10 V will have a corresponding LSB value of $10/2^3=1.25$ V. That is not very good! Similarly a 12 bit ADC will have the LSB value of $10/2^{12}=10/4096=2.44$ mV. If one needs to detect smaller changes, one has to use a higher resolution ADC. Clearly, the resolution is an important characteristic of the DAQ board (Penn Engineering, 2013a).

2.5.2.3 Multiplexing

Common methods to collect more than one signal onto a single ADC. The ADC samples the first channel, switches to the second channel, then third channel, and so on. Because one ADC sampled many channels instead of one, the effective rate of each individual channel is inversely proportional to the number of channels sampled. For example, a PCI-MIO-16E-1 sampling at 1. MS/s on 10 channels will effectively sample each individual channel at 100 kS/s per channel (Physweb, 2013c).

2.6 Current research on DAQ systems

Data acquisition can be employed in every field where sensors and actuators are used. Currently there is a lot of research that is dependent on data acquisition. The following are some of the examples.

2.6.1 Data acquisition of digitized virtual human (US National Library of Medicine, 2013)

The study of digitized virtual human is a new field of medical science research that still requires long-term dedicated effort to reach its full development. Among the research projects of the integrated Virtual Chinese Human, four essential constitutional opponents must be included, i.e. virtual visible human, virtual physical human, virtual physiome, and intellectualized virtual human. Solving the problems concerning the data acquisition for the dataset of this immense project should be of primary importance. Currently 9 virtual human datasets have been established

worldwide. In the paper published by US national Library of Medicine the datasets are subjected to critical analyses and special attention is given to the problems in the data storage and the methods utilized, in these datasets. The authors of the paper propose some countermeasures for solving the problems in the data acquisition for the dataset, which include (1) giving the priority to the quality control instead of capitalising on quantity and speed, (2) improving the setting up of the markers specific for the tissues and organs to meet the requirement from information technology, (3) giving attention to the development potential of the dataset which should have explicit relevance to specific actual applications.

- 2.6.2 Fundamental understanding on the use of Bluetooth scanner as a complementary transport data was discussed (Bhaskar, Kieu, Qu, Nantes, Miska & Chung 2013).

The research looks at usage of blue tooth to transport data that is acquired by DAQ devices from transport facilities within a radius of 100 m. The performance of the system is highly limited by the reliability of blue tooth signals. Although the research is mainly about Blue tooth; some work have to be done on data acquisitions as they are the sources and destination of Blue tooth transmitted signals.

- 2.6.3 Programmable data acquisition system for research measurements from meteorological radiosondes was discussed (Harrison, Nicol & Lomas 2012).

A research that focuses on the use of the DAQ equipment which is carried by balloons onto the atmosphere to capture parameters that are later used for the prediction of future climate conditions. Its architecture supports four analog inputs with 16 bit resolution, and up to two further inputs at lower resolution configurable instead for digital instruments. This DAQ equipment provides multiple instrument power supplies (+8V, +16V, +5V and -8V) from the 9V radiosonde battery. During a balloon flight temperatures may change from +17°C to -66°C, that resulted to a worst case voltage drift of 20mV in unipolar digitisation circuitry. This system enabled a new range of low cost atmospheric research measurements, by utilising radiosondes routinely launched internationally for weather forecasting purposes. The systems require no additional receiving equipment. Comparisons between the specially instrumented and standard meteorological radiosondes show negligible effect of the additional instrumentation on the standard meteorological data.

2.6.4 A low power high speed dual data rate acquisition system using FPGA

Practical approach on interfacing high speed dual data rate (DDR) ADC with FPGA was discussed (Tiwari, 2012). Digitized data from the mentioned ADC is collected from both the rising and falling edges of the sampling clock. This concept offers the following advantages:

- low power consumption,
- low demand of resources,
- and better accuracy of clock to data alignment.

2.6.5 A multifunctional data acquisition system for photovoltaic plants

Development of a multi purpose data acquisition used to collect various environmental and operational signals derived from photovoltaic plants was discussed (Bian, 2012). Data acquisition systems collect data that is derived from AC currents, DC currents, AC voltages, DC voltages, ambient temperatures and power quality. The DAQ circuitry communicates with the host computer that runs an application that was written using LabVIEW.

2.6.6 Design and performance evaluation of networked data acquisition systems based on Ethernet for Control Automation Technology (EtherCAT).

Performance of industrial communication networks was studied and discussed (Junyan, 2010). High speed networked data acquisition took an advantage of high performance industrial communication networks. In this research, the performance of networked data acquisitions was evaluated and a report of verified results is given.

2.7 Research that is similar to this one:

No project or research was found to be 100 percent similar to this one. The following are examples of research that have some attributes which are common to those in this research:

2.7.1 Design and Development of Low Cost Multi-Channel USB Data Acquisition System for the Measurement of Physical Parameters was discussed (Nungleppam, Kanak & Nungleppam 2012).

This low cost data acquisition unit has been designed with a goal to use it for measuring of physical parameters such as temperature, humidity, light intensity etc. These slow varying signals are sensed by respective sensors or integrated sensors and converted into voltages. This DAS uses a PIC18F4550 microcontroller and communicates with the Personal Computer (PC) through USB (Universal Serial Bus). The host computer controls the DAS functionality by using an application that was written in Visual Basic. That allows online monitoring in graphical as well as numerical display.

2.7.2 The use of microcontrollers for data acquisition was discussed (Szarek 2003, p.3)

This board uses embedded data acquisition system in the real world. In his paper, the researcher wrote that the two Conventional data acquisition devices will not perform similar functions. Two experiments were conducted with this device. The first one was to determine the altitude achieved by a model rocket and the other one to measure the surface temperature distribution of a lake. A rocket payload consisted of the required electronics that included an accelerometer to measure the rocket's acceleration and a pressure transducer to measure the rockets velocity. In the second experiment, an electric-powered boat loaded with thermocouple to measure the water temperature and a Global Positioning System (GPS) to determine the boat's location were used.

2.7.3 PIC12F675 Microcontroller Based Data Acquisition System for Slowly Varying Signals. (N. Monoranjan Singh, K. C. Sarma, 2012)

A PIC12F675 microcontroller was used to build a cost effective, low cost four channel data acquisition card for slow varying signals. The host computer with an application that was written by using visual basic connects to DAS via its serial port. A Pick 2 programmer is used to program the onboard PIC microcontroller. A collected data is used to plot graphical representation of the incoming signal and values numerical values can also be recorded from the input varying signals.

This can form a useful Biomedical Instrument in the measurement of arterial pulse, ECG, Electroencephalogram (EEG), etc.

Chapter 3

Research methodology

3.1 Introduction

This chapter focuses on research methodology. Procedures to be followed when evaluating both conventional and embedded data acquisition systems are explained. Also an ideal DAQ system's output results and factors other than errors; that will have an impact upon its performance are explained.

3.2 Experiments that are conducted within this experimental research.

This is an experimental research; therefore quantitative data will be gathered from conducted experiments. The test of data acquisition cards will be limited to slew rate, settling time, relative accuracy / integral nonlinearity (INL) and system noise. For more details on slew rate and settling time refer to Figure 1 below. Parameters such as resolution, sample rate, multiplexing, etc will not be tested. The untested parameters can be read directly from data sheets when required. After completing these tests, performance specifications will be documented, and then the overall performance of embedded DAQ system will be compared to that of conventional DAQ system.

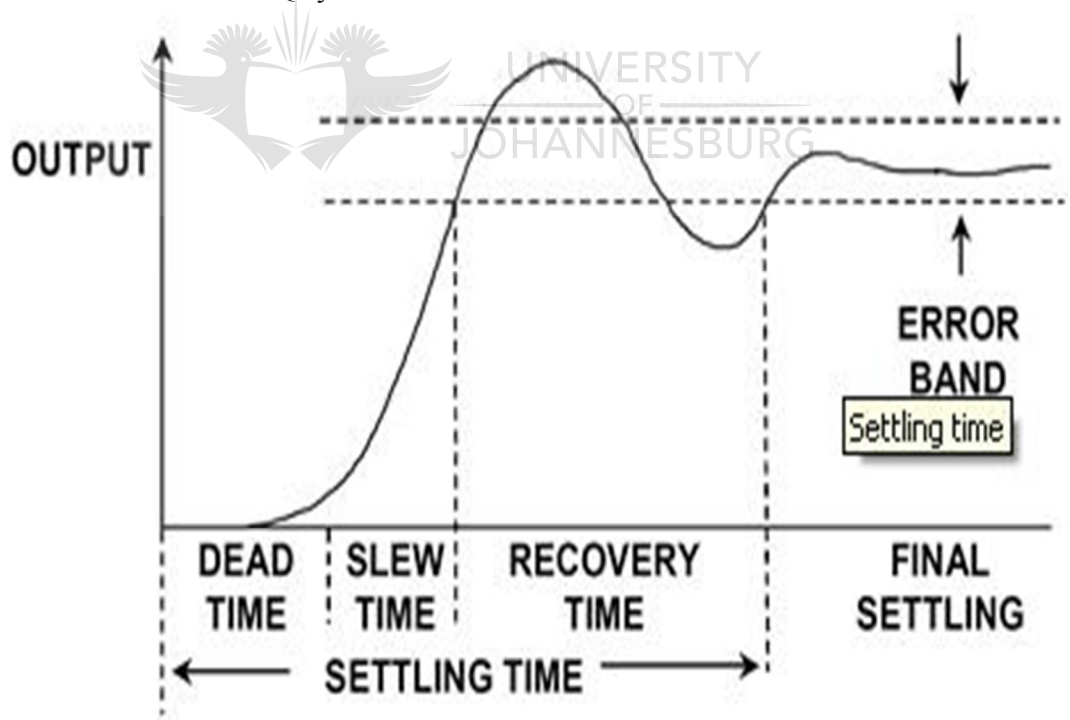


Figure 1: Waveform that illustrate slew rate and settling times

3.3 Analog output from an ideal DAQ system

The analog output section of a DAS is driven by the digital to analog converter (DAC). In this research this digital to analog converter will receive binary values from the processor. A number of bits (n) that are applied to the DAC at a time determine the DAQ system's resolution.

A DAC requires reference voltage for it to successfully convert each binary value at its input to a corresponding analog value. Each input binary value will be multiplied by the reference voltage and then divided by the possible maximum value that a DAC can take. In this way, the DAC will translate binary values onto analog values.

Refer to Figure 2 for an output given by ideal DAQ system. In Figure 2 the red blocks were supposed to form a smooth straight line but since binary values are discrete, a closer look to the output signals will reveal stairs. The greater the amount of bits used (resolution), the lower the stair height becomes. A stair height is also low at low voltage values. A stair height is called 1 LSB, voltage resulting from a change of one least significant bit.

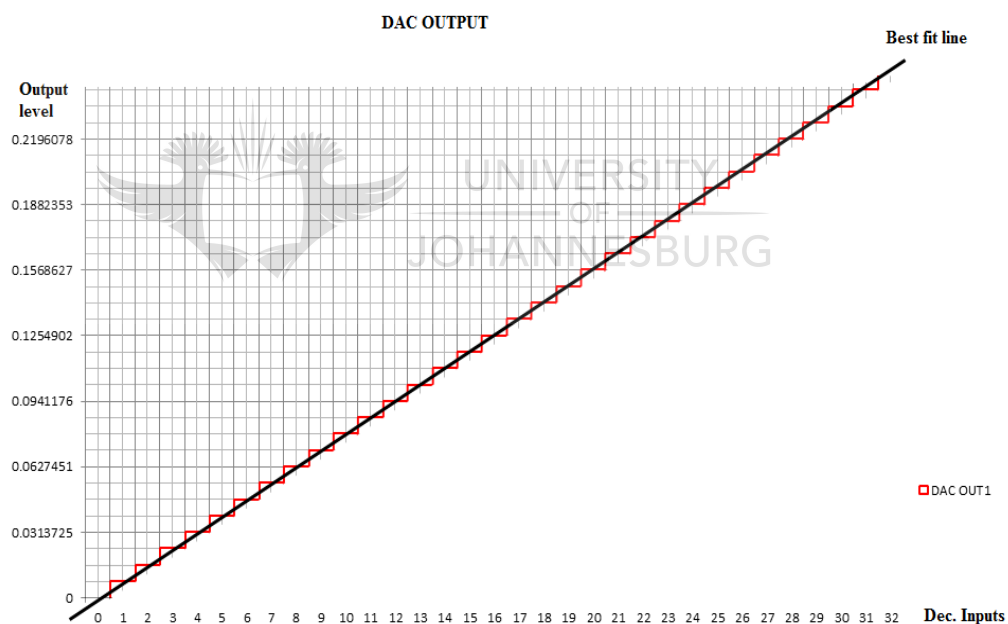


Figure 2 An Ideal DAC output

Figure 2 in an ideal DAC's output, i.e. a DAC without any form of errors. The entire staircases which are shown can be joined by a perfect straight line called a best fit line. Zooming onto each stair will reveal that it takes **no time for each stair to rise** from minimum to maximum value, each stair is **perfectly flat at the top** and that each **stair is perfectly superimposed with the best fit line**.

Real DAS will give output stairs with all properties that are illustrated by Figure 1, namely: slew rate, settling times and relative accuracy.

3.4 Methods for evaluating embedded and conventional DAQ systems

It is extremely impossible to directly measure slew rate, settling, and relative accuracy (INL) by using modern instruments such as oscilloscopes. One of the challenges is that some oscilloscopes are also DAQ systems; therefore they will introduce their own acquisition related errors. Data sheets can not provide a solution because they often provide specifications at a component level.

Figure 3 shows an oscilloscope display that you have to analyze as an attempt to directly measure slew rate, relative accuracy and settling times. The signal is highly affected by noise since it is just a representation of 1 bit level change, therefore it is weak. This signal represents voltage value given by a change of one least significant bit (LSB). $1 \text{ LSB} = V_{\text{ref}} / 2^n$. Where n is the total number of converted bits, in this case 8 bits were used. From this wave: $1 \text{ LSB} = 58.12 \text{ mV}$, therefore the reference voltage = $58.12 \text{ mV} \times 256 = 14.8992 \text{ V}$. This is a correct value for the reference voltage. Amplifying this won't help; how many transitions are you going to amplify before you get the right result? An 8 bit DAS will provide 256 of this. And how will you choose right position for measurements with reference to the best fit line?

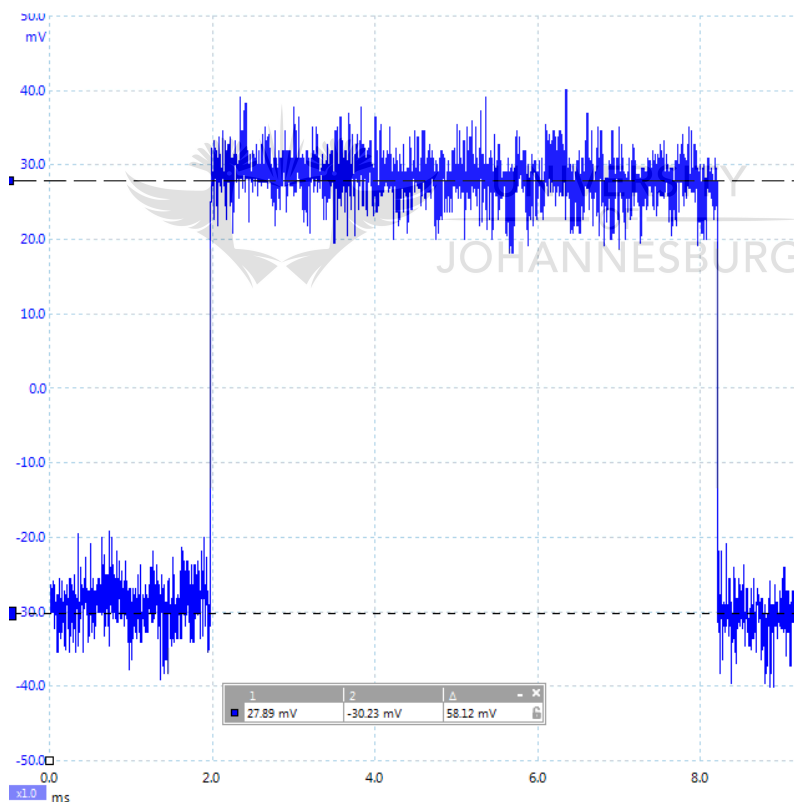


Figure 3 Output voltage waveform given by 1 LSB signal

In this research, specifications of different DAQ cards are compared. The most critical outcome are illustrations which compare different types of DAQ cards under test and to check whether slew rate, settling times and relative accuracies of these DAQ cards are stable over both the voltage and frequency domains. For this kind of analysis, accuracy of the actual collected values will not affect findings.

When a triangular or saw tooth wave is displayed by a digital oscilloscope, the stairs can be seen when using the zooming feature. In this research, the stairs were found not to be exactly 1 LSB of an input wave.

Refer to Figure 4. The signal in Figure 4 has a level of 89.39 mV and the DAS used has a 20V reference voltage. $1 \text{ LSB} = V_{\text{ref}} / 2^n$. Therefore $89.29 \text{ mV} = 20\text{V} / 2^n$; therefore $n = [\log (20 \text{ V} / 0.08929 \text{ V})] / \log 2$, $n = 87$ bits. It is not possible for for the pulse mentioned to be resulting from 87 bits. Most probably this is a calibrated output result. Therefore Figure 4 is a version of the signal represented by Figure 3 that has unknown gains and offsets. Although the signal represented by Figure 4 is not a 1 LSB representation, it does have most properties of a 1 LSB signal. This specific type of pulse will be used as reference in all LSB calculations that will follow. In all cases this reference pulse is selected at a point where is highly symmetrical around the best fit line. The reasons it was chosen are : 1) it can be easily identified, 2) it has a lower and consistent settling time, 3) most importantly, on one waveform all this type of pulses are we found to be well positioned to the best fit line.

From this type of pulses; slew rates, settling times and relative accuracies will be estimated for all DAS that are used in this research. All Relative accuracy values that are obtained will be referred to as virtual. It is already been proved that the amplitude of the signal represented by Figure 4 is not a 1 LSB value, but rather proportional to 1 LSB value.

To get the final relative accuracy estimation, two more pulses; one with worst deviation from best fit line and the other one with least deviation from best fit line are located. The error is calculated, by taking the difference in amplitude of each mentioned pulse with the amplitude of pulse that is similar to the one given by Figure 4 and then the final error is estimated by calculating the average error between the two. Taking the difference between two output pulses coming from the same output source cancels any offsets that were applied to the original pulses e.g. $(A + \text{OFFSET}) - (B + \text{OFFSET}) = A - B$.

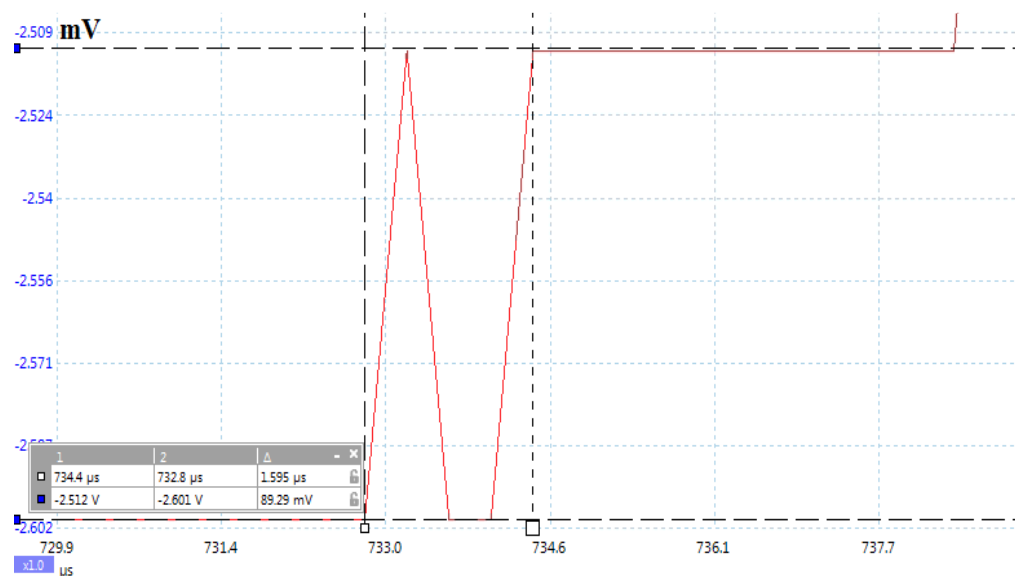


Figure 4 Reference signal for relative accuracy estimations

Figure 5 on the next page is typical full oscilloscope display that was used when estimating relative accuracy, settling time and slew rate. Note that the diagram only illustrates a zoomed section that covers both the signal and best fit line. The best fit line actually spans over the entire signal range. The signal was produced by myDAQ data acquisition system and the best fit line was drawn by using “maths channel” feature. It is interesting to realize that the method used to determine settling time and slew rate is true, however the question that was already answered is how to get 1 LSB change that is required when determining relative accuracy.



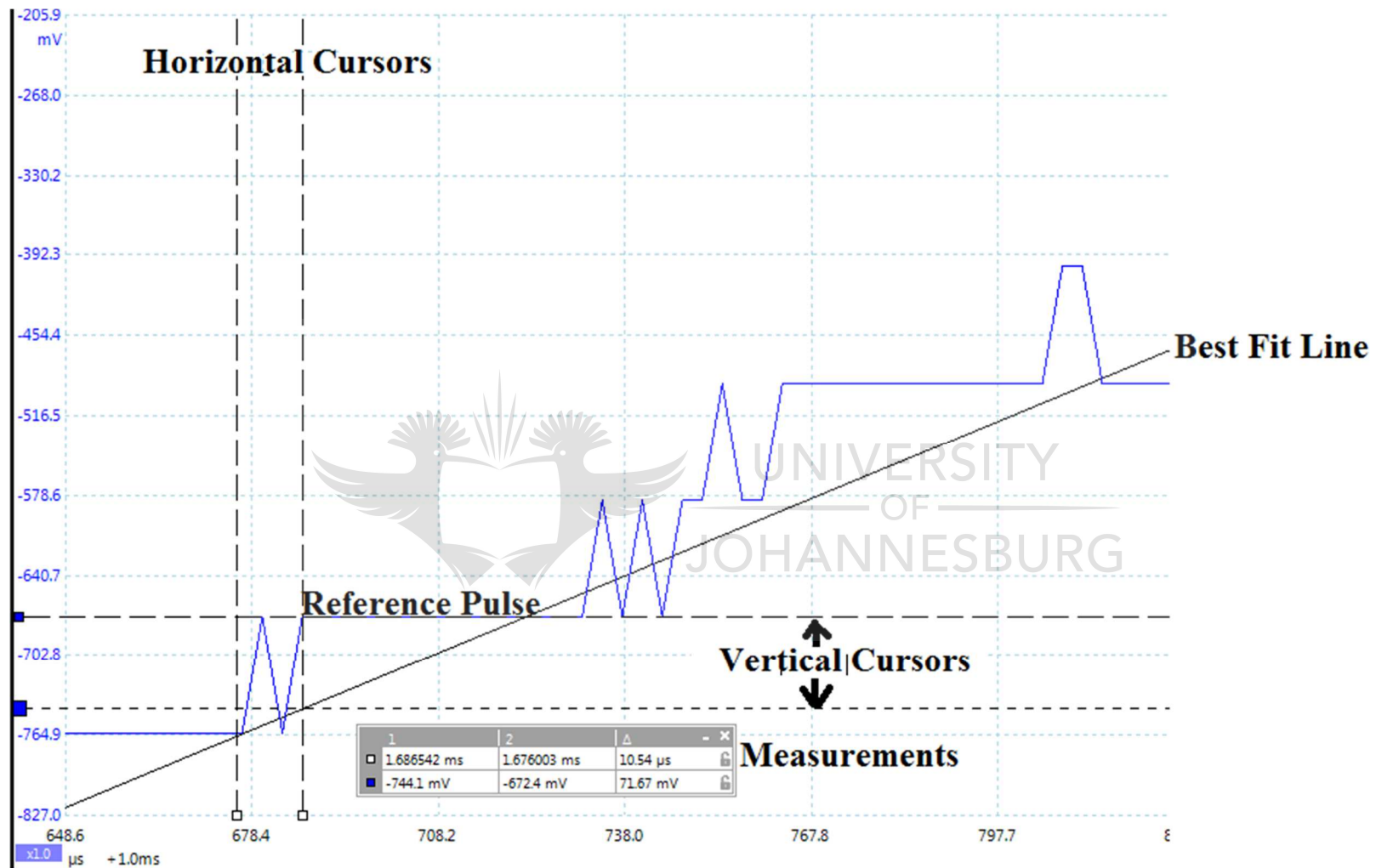


Figure 5 Relative accuracy and settling time from reference pulse

3.4.1 Measuring Settling time

When a DAQ system's voltage changes from one level to next, it will take it a short duration for it to settle on a constant amplitude level. Adding to the rise time (Time for the pulse to grow from 10 % to 90 % of its maximum value); there will be oscillations that occur at peak of this pulse. Figure 1 in section 3.2 illustrates the oscillations and their duration. Settling time will also be used as a parameter that highlights the DAQ speed. A DAQ with a small settling time can generate high-frequency signals because little time is needed to accurately change the output to a new voltage level (Physweb, 2013b).

3.4.1.1 List of equipment

- 1 X Saw tooth or triangular wave generator
- 1 X Digital Oscilloscope with a capability to save and Zoom
- DAQ cards to be tested
- Connecting leads
- Note book and a pen to record results

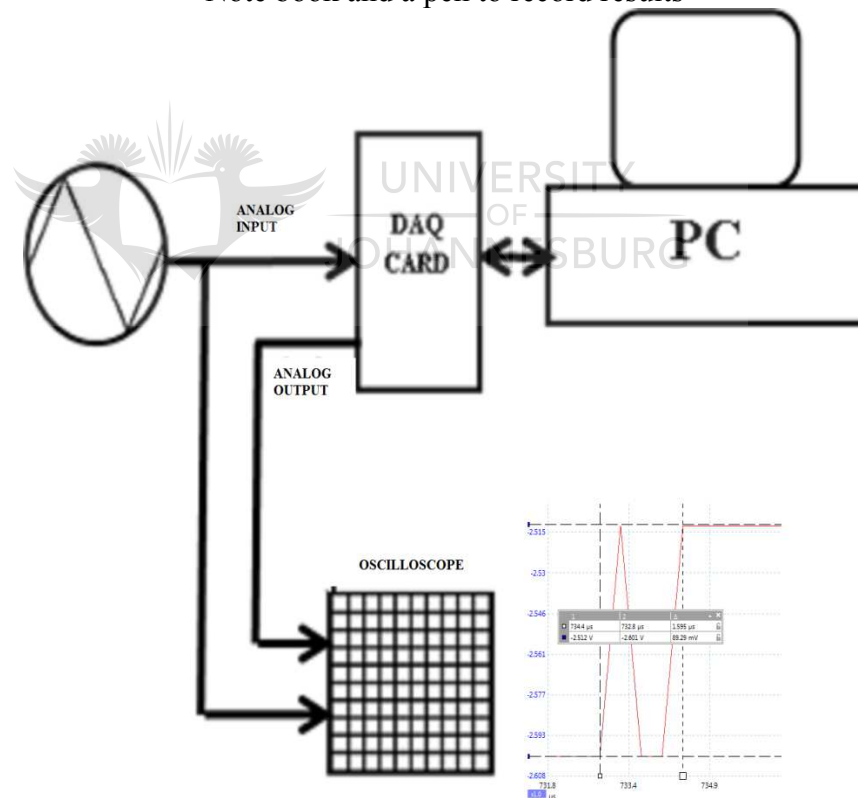


Figure 6 Equipment setup for settling time measurements

3.4.1.2 Procedure

- connect the equipment as illustrated by Figure 6.

Conventional DAQ systems only

- Feed the triangular wave to the DAQ card's analog input channels as shown.
- Connect channel 1 of your oscilloscope directly to the saw tooth wave generator.
- Connect channel 2 of your oscilloscope to the DAS analog output.
- Run LabVIEW code that was designed to loop back the signals.

Embedded DAQ systems only

- Connect channel 1 of your oscilloscope to the DAS analog output.
- Program the embedded DAQ with the code that was designed to generate a saw tooth wave. Or run the LabVIEW program that was designed to generate the triangular or saw tooth wave.

Place oscilloscope's horizontal cursors on appropriate positions for settling time measurements.

3.4.2 Measuring Slew rate

Slew rate can be measured at rising edge of a voltage pulse illustrated by Figure 1 in section 3.2; it is given by change in voltage over change in time. Therefore a fast rising pulse will have high slew rate when compared to slow rising pulse. We will use this parameter to highlight a DAQ card with capabilities to produce high frequency. A DAQ with a high slew rate can generate high-frequency signals because of the little time that is needed to accurately change the output to a new voltage level (Coates, 2007).

Components, diagrams and procedures are similar to the one used in section 3.4.1. The only change is in the positioning of the cursors.

- Move the horizontal cursors to positions suitable to measure rise time.
- Move the vertical cursors to the position for the peak to peak voltage and calculate rising rate in kV/ ms.

3.4.3 Measuring Relative accuracy

DAQ systems often suffer from non-linearity and relative accuracy errors, integral nonlinearity (INL). Relative accuracy will be measured and compared amongst DAQ cards. We will use this parameter to identify a DAQ card that has the most nonlinear response.

3.4.3.1 How to measure relative accuracy

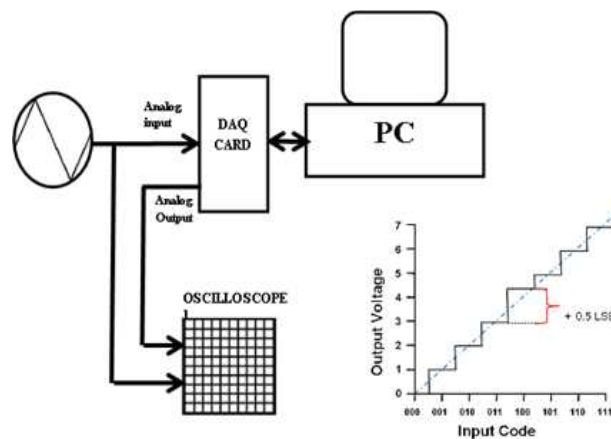


Figure 7 Equipment setup for relative accuracy

Figure 7 illustrates effects of relative accuracy and the wiring diagram used during tests. Equipment, diagrams and procedures are similar to the one used in section 3.4.1. The only change is the inclusion of the best fit line and the positioning of the cursors during the tests procedure. From the oscilloscope display; we take the difference between actual outputs of the reference pulse the best fit line. The difference is then translated to the number of least significant bits that produce it.

3.4.4 Measuring System noise

This is a measure of the amount of noise added by the analog circuit when the analog inputs are grounded at the I/O connector. For signal conditioning accessories, this specification is given in V_{rms} (National Instruments, 2013g). In this section, noise level given by various conventional DAQ cards will be measured and then compared with the one produced by proposed embedded DAQ cards.

3.4.4.1 List of equipment

- 1 X Digital spectrum analyser (Optional)
- 1 X Digital Oscilloscope
- 1 X Digital multimeter
- 2 or more DAQ cards to be tested
- Connecting leads, Note book and a pen

3.4.4.2 Procedure

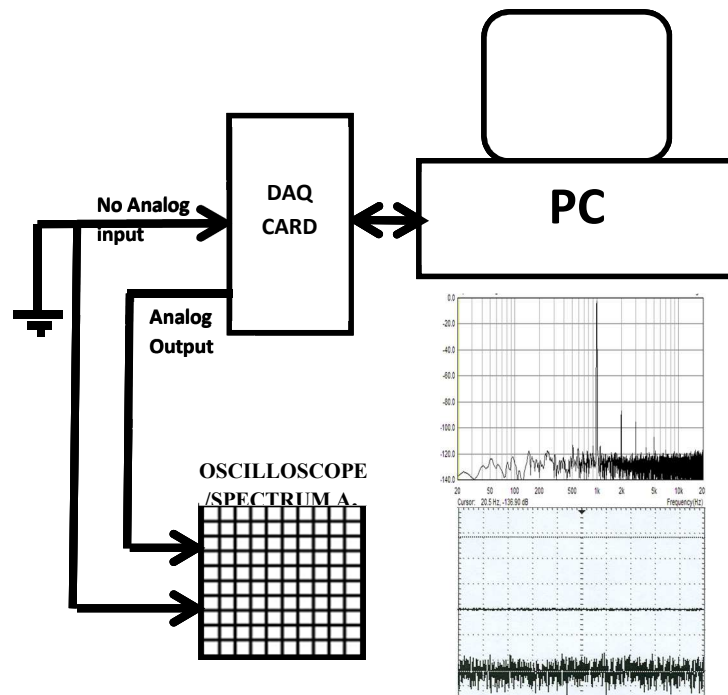


Figure 8 Equipment setup for system noise

- connect the equipment as illustrated by Figure 8
- Ground the analog inputs of the conventional DAQ card which is under test or erase the flash of an embedded DAQ system.
- Run a LabVIEW code that acquires the input signal. (Conventional DAQ only)
- Using an Oscilloscope and spectrum analyzer, display the output signal from the DAQ card.
- Record noise Figure of the DAQ card, save and print.

3.5 LabVIEW programs

For the DAQ cards with existing drivers, LabVIEW program will communicate with these DAQ cards in three ways:

3.5.1 National Instruments Measurement & Automation Explorer (NI MAX)

This is an application which runs outside LabVIEW environment. It is like a template that enables fast and easy connectivity to DAQ cards. Once run, first window will show a list of any connected devices. After a specific device has been selected, device self-test can be performed. Device pin outs can also be displayed to assist you with connections. Two major types of tasks can be created here: input task that collect data from inputs or output task to send data to the outputs. For all tasks a wiring diagram that is based on selected configurations can be displayed.

Data can be displayed in a table or chart format. Scales are adjustable on both the domain and the range. It is important for a person adjusting scales of the graph to have an idea about the signal to be shown. Any task that you create here can be exported to form a LabVIEW code.

This tool was used to verify communications between conventional DAQ systems with the computer. The tool cannot be used with the proposed embedded DAQ since there are no drivers which support that.

3.5.2 DAQ assistant in LabVIEW

Unlike NI MAX this is not an application, it is a tool found in the LabVIEW development environment. LabVIEW environment is divided in two major sections i.e. front panel, where the user place controls such as knobs, buttons graphs, etc. and block diagram, that is where programming takes place with an aid of blocks called virtual instruments (VIs). In the block diagram screen, data flow is specified by interconnecting VIs together.

When using LabVIEW to communicate with DAQ cards, DAQ assistant can be used to complete the task effectively. Under the properties window of the DAQ assistant we are able to set the task as either an input or output task and select a method to display data which can either be a table or a chart that has adjustable scale.

The two diagrams in Figure 9 in this section show two screens that are given by LabVIEW's DAQ assistant. On the left hand side is the properties box and the right hand side is the front panel of running Task.

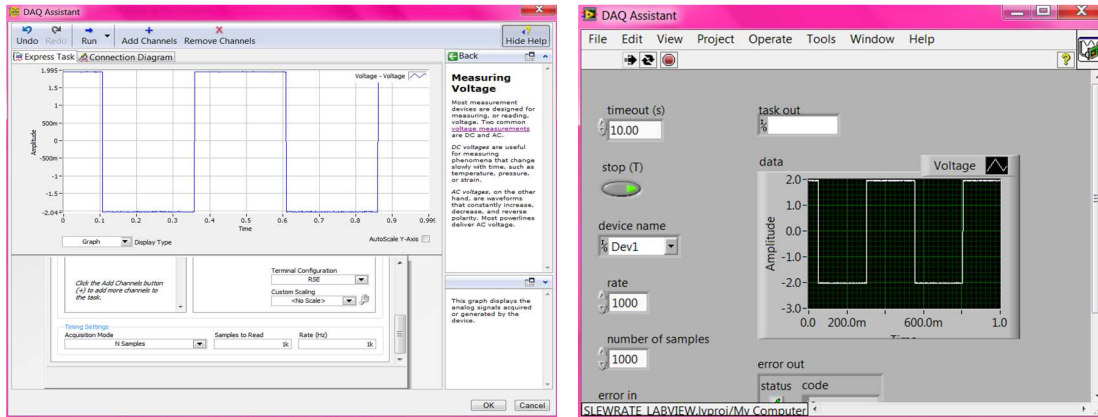


Figure 9

DAQ assistant properties window

LabVIEW Display (1 Hz)

No visible Slew rate and Settling time.

Front Panel in LabVIEW

During these tests, DAQ assistant was used to create a program that acquired signals from one channel at the analog input of a conventional DAQ card and then send it out to one channel of the analog output. It is very important for the speed at which data is acquired to match the one at which data is sent out; otherwise there will be data overflow.

DAQ assistant cannot be used to communicate with the proposed embedded DAQ because there are no drivers to support it. When installing National instrument LabVIEW all latest drivers must be installed from a separate disc and more drivers can be obtained online. When new DAQ equipment is released, its drivers are added to LabVIEW versions that are not older than plus minus three years. So if DAQ assistant is unable to detect the conventional DAQ card, it might be because an older LabVIEW version is used or that drivers were not installed.

3.5.2.1 Step by step procedure to create test program for conventional DAQ cards (myDAQ) by using DAQ assistant

The following steps must be followed to create in LabVIEW, the application to acquire a waveform that is being fed into one of the inputs channel of a conventional DAQ and then pass it to the DAQ system's analog outputs. This procedure is based on a DAQ card called MyDAQ (National Instruments, 2013a).

1. Launch LabVIEW.
2. In the block diagram screen, locate and place DAQ assistant.
3. Open the configuration screen by right clicking DAQ assistant and then select properties option. Now refer to Figure 10

4. In the DAQ Assistant configuration window, select Acquire Signals» Analog Input, and click Voltage to select a Voltage task.
5. Configure voltage channel 0 by selecting Voltage_0 in the Channel Settings pane. Set the voltage to the desired range.
6. Under Timing Settings, set Acquisition Mode to Continuous Samples. Enter the number of samples to read e.g. 5000 and the value of sampling rate e.g. 40000.
7. Exit the DAQ assistant.

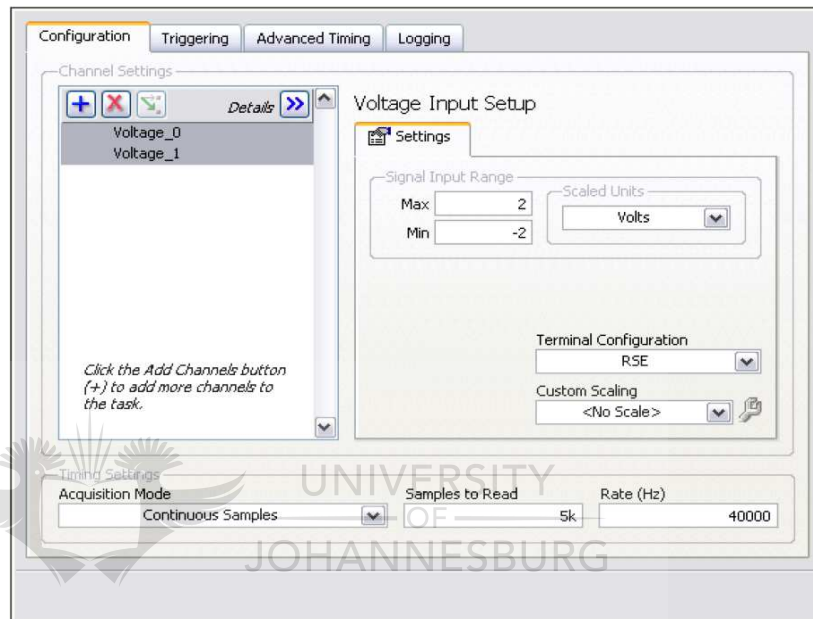


Figure 10 DAQ assistant properties window

8. Place the second DAQ assistant.
9. In the DAQ assistant configuration window, select Generate Signals >>Analog Output, and click Voltage to select a voltage task. Now refer to Figure 11.
10. On the configuration window, configure channel 0 by selecting VoltageOut_0 in the channel setting panel, and then set minimum and maximum voltages in Signal Output Range panel to desired levels.

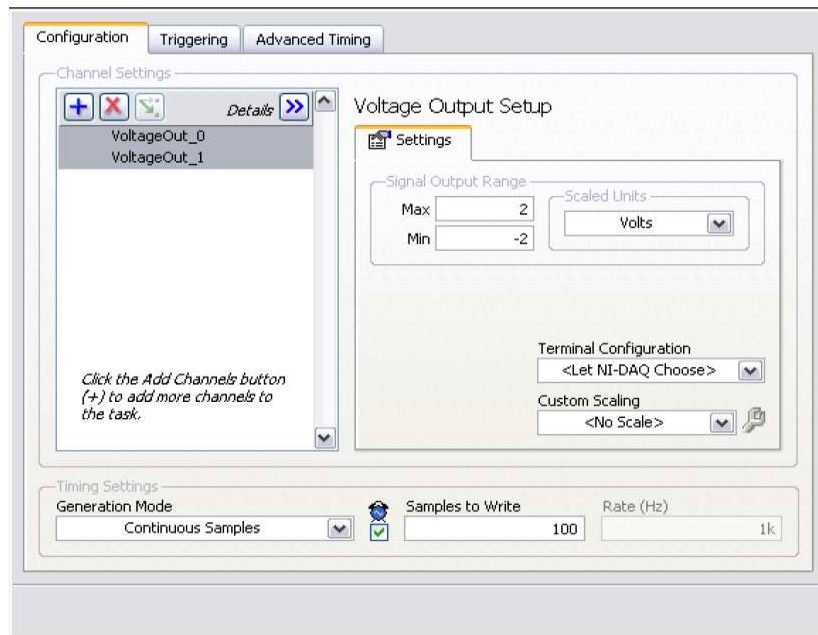


Figure 11 DAQ assistant properties window

- 11 Connect the two DAQ assistant as shown in Figure 12.
- 12 Enclose the two DAQ cards in a while loop.
- 13 Add the stop button.
- 14 Run and test the code.

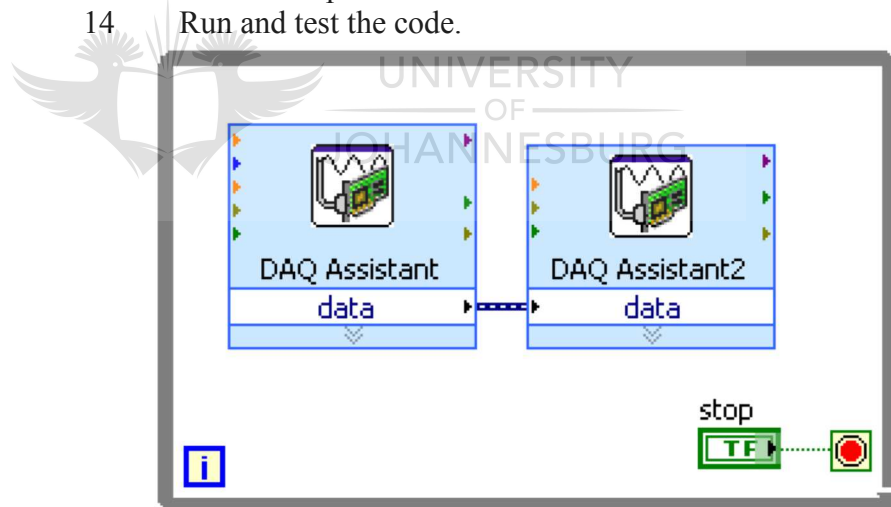


Figure 12 LabVIEW block diagram. MyDAQ test code.

3.5.3 Creating program in the Blank VI

This method can be used on both conventional DAQ systems and the proposed embedded DAQ system. With the conventional DAQ system, drivers must be present as they will be required to control all operational activities. As for the proposed embedded DAQ, serial and USB ports will be used for all communication protocols

3.5.3.1 Step by step procedure to create test program for conventional DAQ cards (myRIO)

Please note that myRIO daq card is not supported by the LabVIEW DAQ assistant.

The following steps will assist when creating a LabVIEW application to acquire a waveform that is being fed into the input channel of a conventional DAQ and then pass it to the DAS analog output. This procedure is based on a DAQ card called MyRIO (National Instruments, 2013b).

1. Make sure that myRio DAQ is connected to the computer. Launch LabVIEW.
2. Click on myRio Project , Browse the Folder, Name File and Click Finish.
3. Right Click on Project, rename it to your preferred name.
4. Click on myRio Project , Browse the Folder, Name Project and Click Finish.
3. Click on myRIO > Right Click Main >Click remove
4. Click on Window > Click on new VI, Give it name and save.
5. Double Click your newly named VI.
6. Click on Window > Show Block diagram.
7. Right Click on a Blank Space > Select myRIO on the dialog box > Click on Analog in Instrument.
8. Right Click on a Blank Space > Select myRIO on the dialog box > Click on Analog out Instrumet.
9. Double Click each on I/O instrument and configure it according to your circuit connections. Figure 13 shows the configurations window.

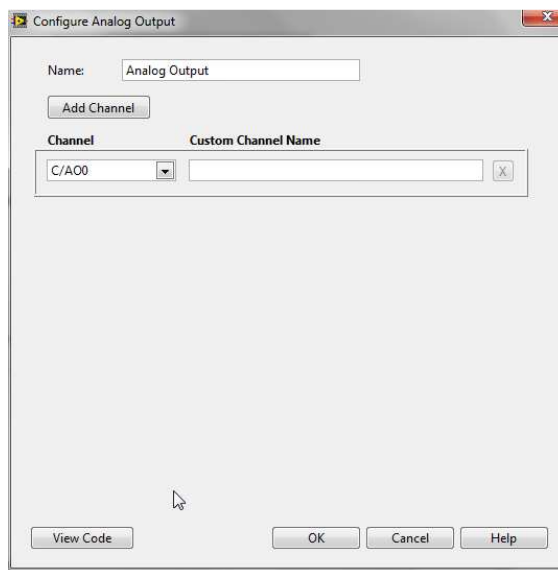


Figure 13 myRIO output channel configuration window

- 10 Right Click on a Blank space > Select programming > Select structure > Click on while Loop.
- 11 Enclose your entire instruments in a while loop by clicking and dragging a cursor around them.
- 12 Click at the output of output of the Analog in drag the cursor to the input of Analog out (connect the instruments).
- 13 Right Click on a Blank space > Select programming > Select Timing > Click on Tick Count.
- 14 Right Click on a Blank space > Select myRio > Select Utilities > Click on Reset myRIO, place it outside the while loop.
- 15 connect the error out of Analog out to the input of “reset myRIO”.
16. Connect the escape button of the while loop to input of “reset myRIO”.

Your code should now look like Figure 14.

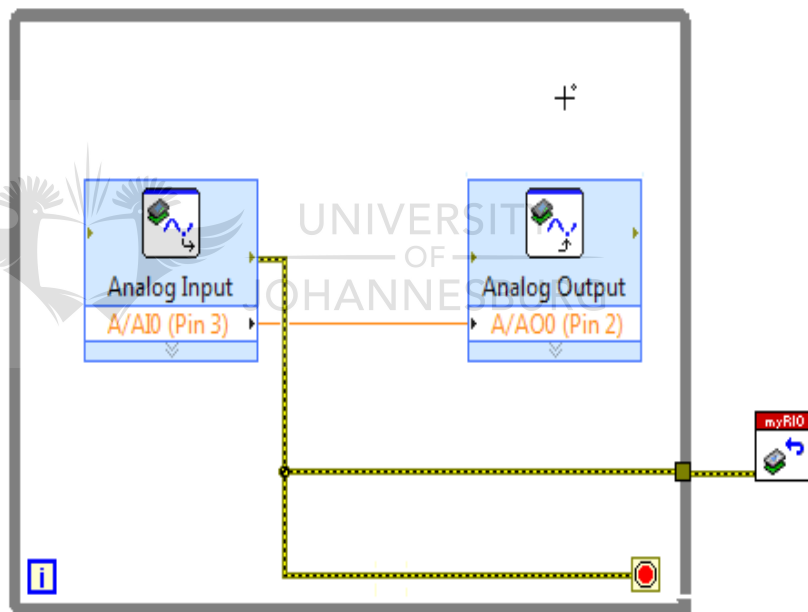


Figure 14 LabVIEW block diagram myRIO test code

Chapter 4

Data acquisition cards test results

4.1 Introduction

The tests results obtained in this section will be used when contrasting the performance between embedded and conventional DAQ systems. As explained in section 1.5 of chapter 1. myRIO and myDAQ are used as examples of conventional DAQ cards, whilst the two PIC Microcontroller based DAS are examples of the embedded data acquisition cards. The embedded DAQ is made up of either PIC18F45K20 or PIC18F97J94 microcontroller that is connected to either DAC0800 8 bit DAC or AD565 12bit DAC. Please refer to the schematic diagrams attached. A DAQ output is a saw tooth wave which is fed to one of the input channels of a USB based oscilloscope. One needs to take two things into consideration when collecting the results that will follow: (1) Collected data is only required for comparison. (2) The oscilloscope itself is a data acquisition device; therefore it is going to introduce its own errors into the results. It is therefore important to study the Oscilloscope errors before using it to collect any DAS results.

4.2 Results from conventional DAQ systems

4.2.1 myRIO results, externally acquired triangular waveform passed by myRio DAS to the oscilloscope.

Slew rate, settling time, relative accuracy and system noise are measured at the analog output 0 or 1 of the DAS channel C, refer to Figure 15. External triangular wave is supplied into the DAS by using analog input -0 and +0 or -1 and +1 of channel C. Output is read from the oscilloscope, oscilloscope errors are taken onto account and then the estimated results are recorded.

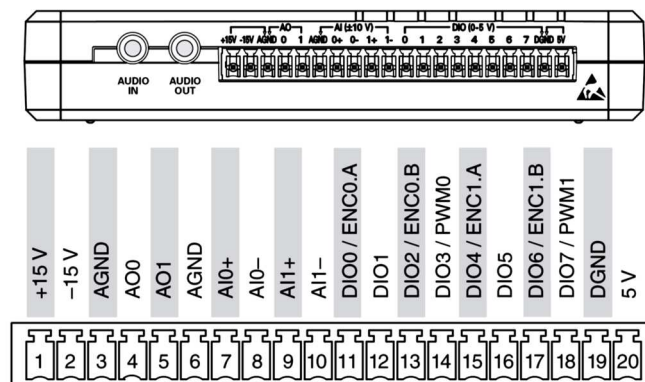


Figure 15 myRIO cross sectional diagram

During this experiment; the waveform illustrated by Figure 16 was displayed on the oscilloscope screen when a 100 Hz triangular waveform with amplitude of 20 V peak to peak was acquired by myRIO DAS and passed to the computer, the host computer then uses LabVIEW code to retransmit its input triangular waveform to the output channel of the DAQ system, where oscilloscope is connected.

The oscilloscope display was studied carefully by identifying the positions where the highest and least values of relative accuracy occur.

Figure 17 shows an area where the settling time is 13.74 μ s, slew rate = 0.056974 kV/ms and. virtual relative accuracy indicated by Figure 17 (in volts) = 38.06 mV. Estimated relative accuracy of Figure 18(in volts) = $[(94.63\text{mV} - 38.06 \text{ mV}) / (20/2^{12})] - 1 = 10.585536 \text{ LSB}$. Note that the reference signal is assumed to be perfect, and these figures are only for comparison purposes

Table 1 gives a summary of all other values on both frequency and voltage domains.

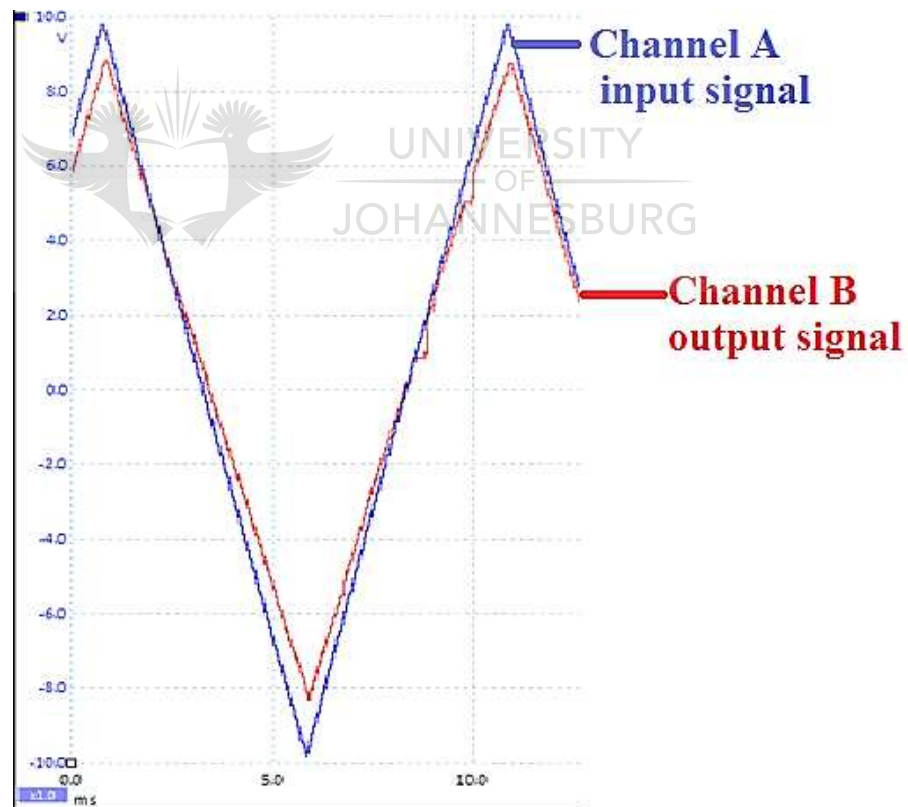


Figure 16 Test signal: 20V peak to peak at 100 Hz

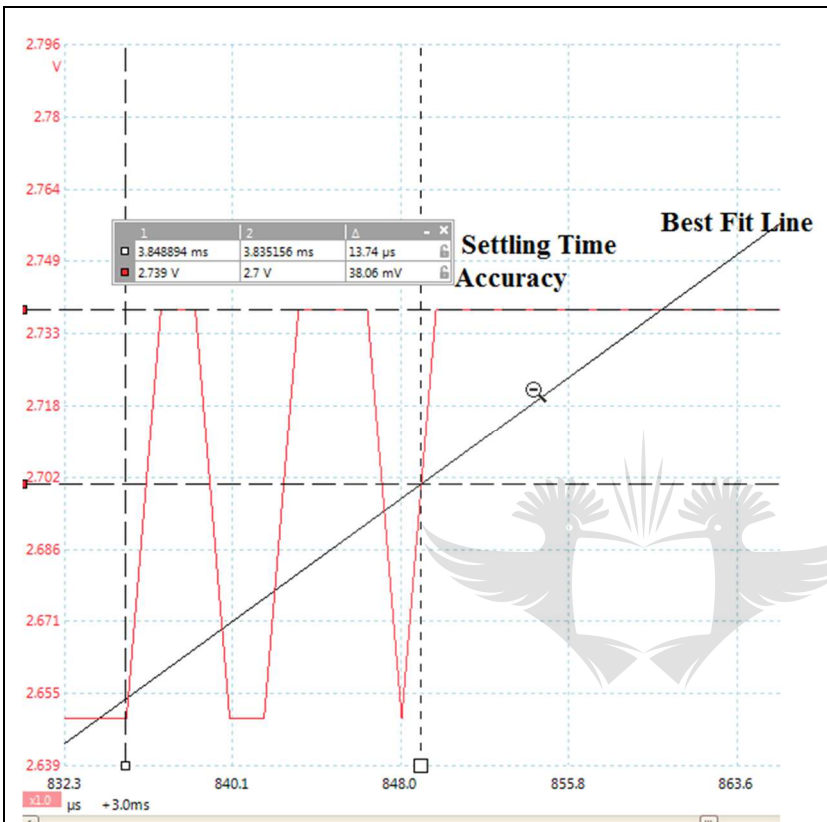


Figure 17 Reference pulse for measurements

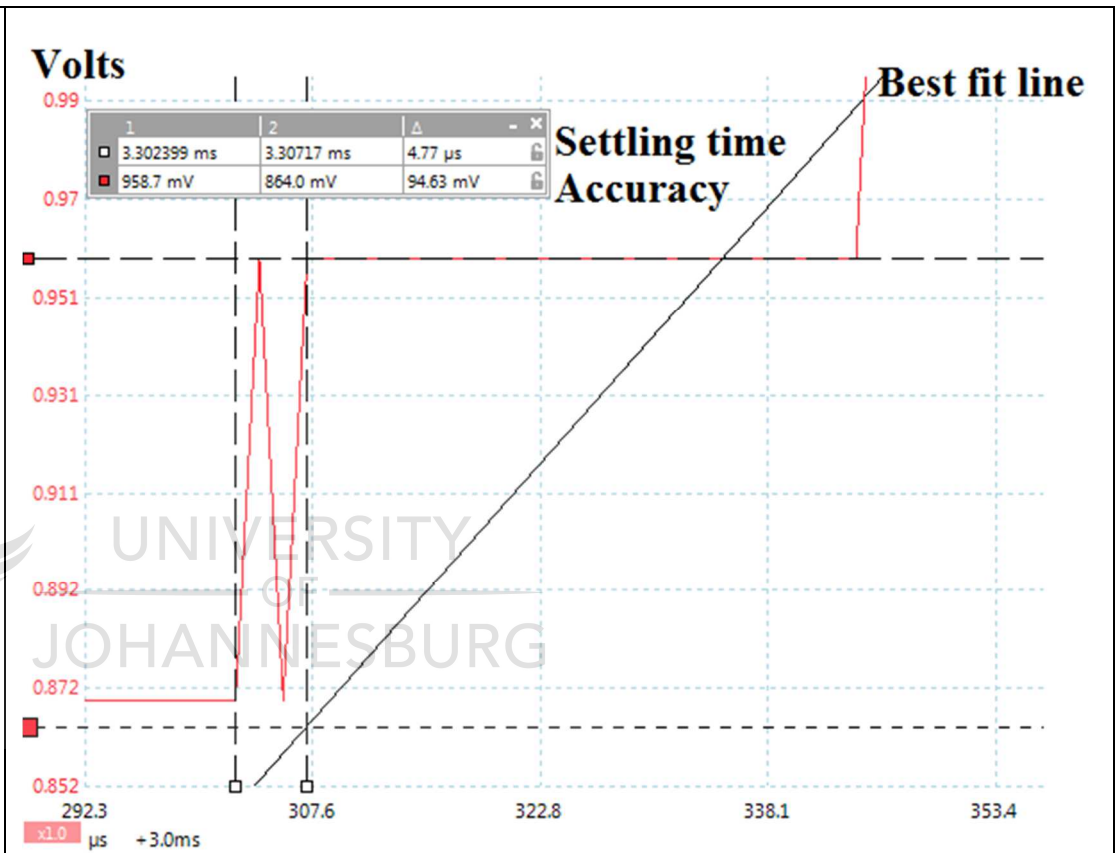


Figure 18 Actual pulse for measurements

Table 1: Results from experiments with myRio DAQ system

V _{P-P} (volts)	Frequency (Hz)	Slew rate (kV/ms)	Settling time (us)	LSB(V)	Virtual relative accuracy		Estimated relative accuracy(LSB)	Comments
					Volts	LSB		
20	100	0.0138735	19.25	0.00488	0.0906	8.28279	8.38012	Varying Frequency
20	300	1.423	4.324	0.00488	1.423	144.799	8.38012	
20	500	0.07353	6.6	0.00488	0.1778	17.2172	8.38012	
20	1000	0.000611	4.23	0.00488	0.8003	80.998	8.38012	
20	3000	----	----	0.00488	----	----	8.38012	
20	10000	----	----	0.00488	----	----	8.38012	
20	150000	----	----	0.00488	----	----	8.38012	
20	20000	----	----	0.00488	----	----	8.38012	
20	25000	----	----	0.00488	----	----	8.38012	
10	1000	0.083209936	41.87	0.00488	1.742	177.4836066	8.38012	Varying maximum voltage
5	1000	0.045105361	37.49	0.00488	0.8455	85.62909836	8.38012	
3	1000	0.014065817	37.68	0.00488	0.265	26.15163934	8.38012	
0.5	1000	0.002171067	38.27	0.00488	0.040665	3.166495902	8.38012	
1	1000	0.0523902	3.096	0.00488	0.018	0.84426	8.38012	Varying frequency
10	100		90.1	0.00488	0.1794	17.3811	8.38012	Highest value
10	100		19.25	0.00488	0.0037	-0.6209	8.38012	Lowest value
10	100		54.675	0.00488	0.09155	8.38012	8.38012	Average

System Noise (peak to peak)	Relative accuracy per data sheet	Settling time per datasheet	Slew rate per data sheet
61.26 mV	Absolute accuracy.= ±200 mV		2 kV/ms (DAC MSP output)

4.2.2 myDAQ results, externally acquired triangular waveform passed by myDAQ data acquisition system to the oscilloscope

Slew rate, settling time, relative accuracy and system noise are measured at the analog output 0 or 1 of the DAQ system. Refer to Figure 19. External generated triangular wave signals are fed into the DAS through the analog inputs -0 and +0 or -1 and +1. The oscilloscope is connected to analog output 0 or analog output 1 where the acquired triangular wave signal is reproduced. Errors are then taken into account, values are calculated or estimated, the results are then recorded.

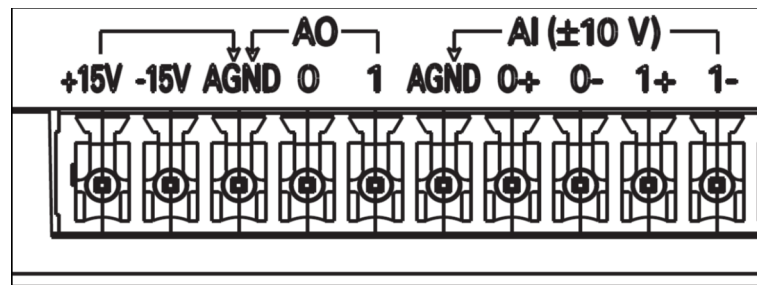


Figure 19 myDAQ cross sectional diagram

During this experiment; the waveform illustrated by Figure 20 was displayed by the oscilloscope screen when a 100 Hz triangular wave with the amplitude of 20 V peak to peak was acquired by myDAQ data acquisition system. Application program that is written using LabVIEW collect signals from the DAQ system’s inputs and forward it to analog output within the same DAQ system. At least one oscilloscope channel is connected to the active output of the DAQ system. Figure 21 is a zoomed section of a selected reference pulse.

Table 2 summarizes all results that were obtained during the tests.

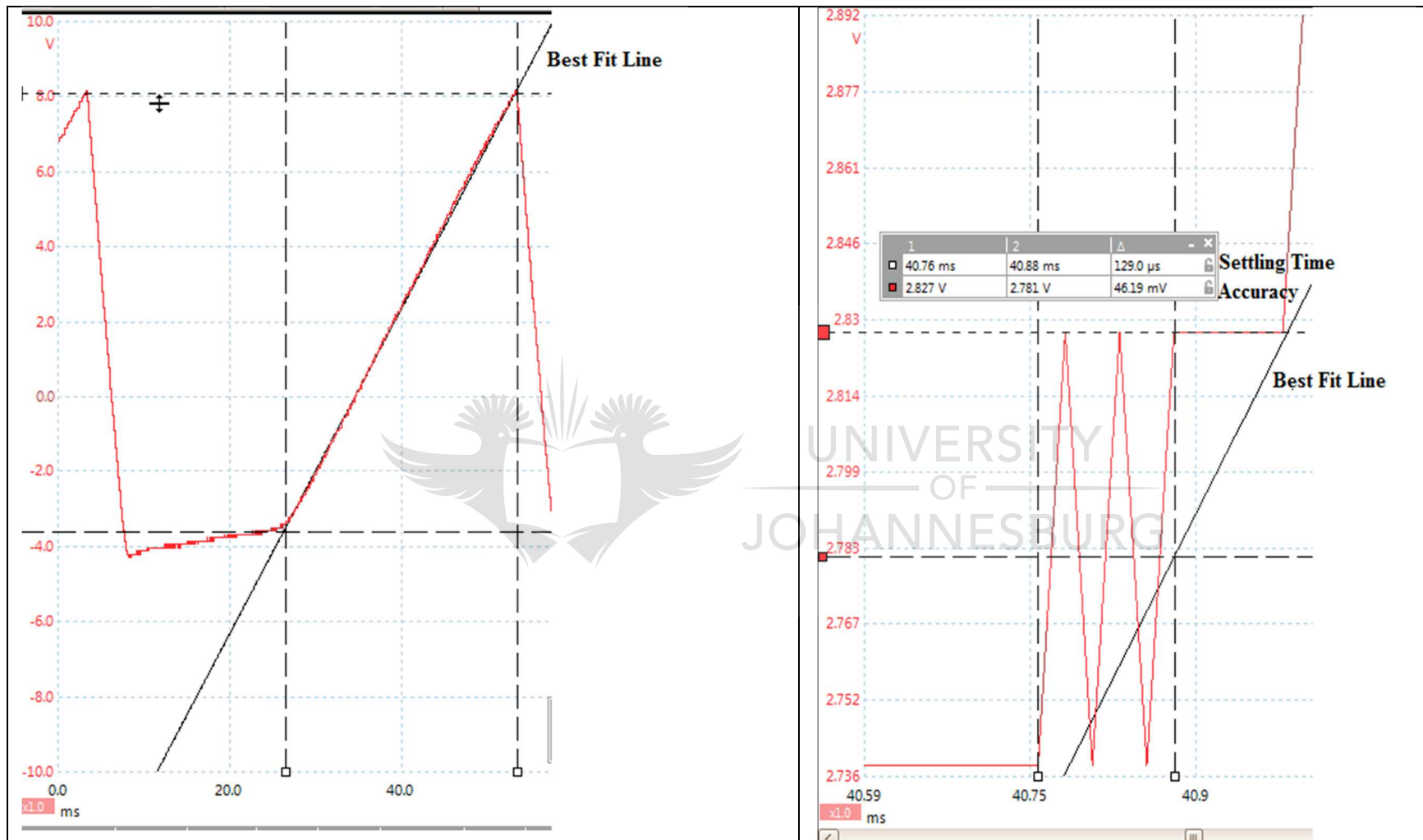


Figure 20 myDAQ test signal: 20V peak to peak at 100 Hz Figure 21: 1 LSB reference pulse of myDAQ external signal

Table 2: Results from experiments with myDAQ DAQ system. (DAQ Externally Generated signals)

V out p-p (volts)	Frequency (Hz)	Slew rate (kV/ms)	Settling time (us)	LSB(V)	Virtual relative accuracy		Estimated relative accuracy (LSB)	Comments
					Volts	LSB		
12.4	100	0.0127258	19.56	0.00031	0.08875	144.396	0.115334207	Varying frequency
10	300	0.2350053	1.177	0.00031	0.08902	144.839	0.115334207	
10	500	0.4140465	0.6081	0.00031	0.08902	144.839	0.115334207	
13	1000	0.4802489	0.5963	0.00031	0.08875	144.396	0.115334207	
10	3000	1.77974886	0.1534	0.00031	0.08929	145.281	0.115334207	
12.4	10000	1.7584704	0.1488	0.00031	0.08875	144.396	0.115334207	
11.32	15000	1.8170533	0.1505	0.00031	0.08821	143.512	0.115334207	
10.12	20000	1.8377374	0.1989	0.00031	0.08875	144.396	0.115334207	
11.46	25000	1.8060643	0.1511	0.00031	0.08875	144.396	0.115334207	
9.37	10000	1.7726822	0.1511	0.00031	0.08902	144.839	0.115334207	Varying maximum voltage
6.9	10000	0.8974359	0.199	0.00031	0.04437	71.69	0.115334207	
2.488	10000	0.1833537	0.3041	0.00031	0.01796	28.4233	0.115334207	
0.9816	10000	0.0747496	0.3041	0.00031	0.00893	13.6281	0.115334207	varying frequency
0.9816	1000	0.0103826	3.286	0.00031	0.00893	13.6281	0.115334207	
12.4	100		19.56	0.00031	0.00054	-0.1153	0.115334207	Highest value
12.4	100		19.56	0.00031	0.00054	-0.1153	0.115334207	Lowest value
12.4	100		19.56	0.00031	0.00054	-0.1153	0.115334207	Average
System Noise		Relative accuracy per data sheet		Settling time per datasheet			Slew rate per data sheet	
		Absolute accuracy = 19.6 mV to 42.8 mV					Slew rate. 4 kV/ms	

4.2.3 myDAQ results, internally generated triangular wave is produced by myDAQ data acquisition card and sent to the oscilloscope.

Slew rate, settling time, relative accuracy and system noise are measured at the analog output 0 or 1 of the DAQ; refer to Figure 19 of section 4.2.2. One of the oscilloscope channels is connected to read signals that come out of the DAQ system. Oscilloscope errors are taken into account and then the estimated results are recorded.

During this experiment; the waveform illustrated by Figure 22 was displayed on the oscilloscope's screen when the input to the DAS was a 100Hz, 20 V peak to peak signal. The internal triangular wave signal is generated by software code that was written using LabVIEW. After great analysis of Figure 22 we can easily determine the following parameters: Settling time = 10.39 μ s, Slew rate = 0.0276 kV /ms and Virtual relative accuracy = 71.42 mV.

Table 3 gives a summary of all other results.

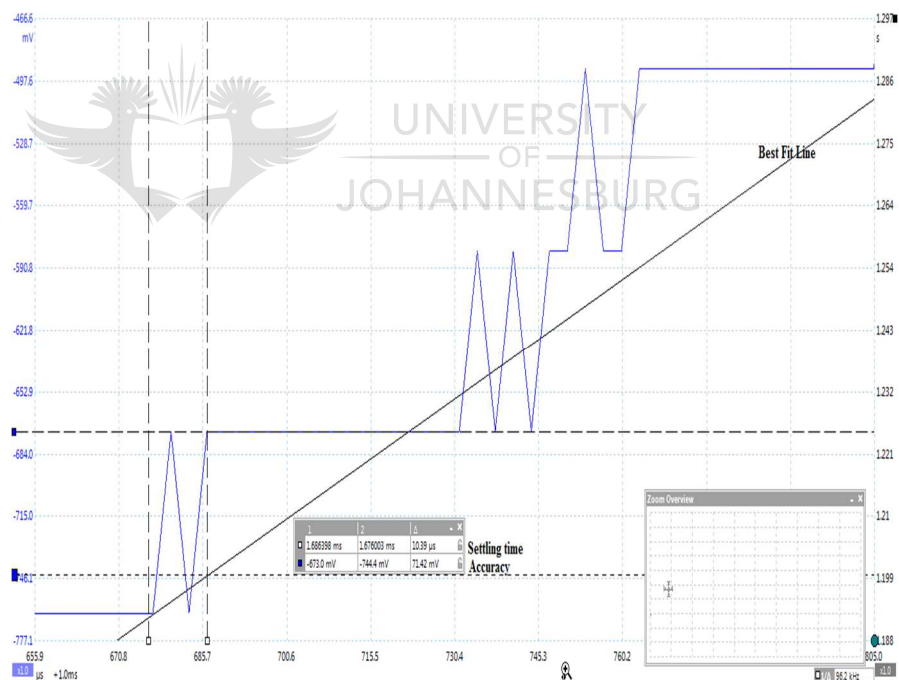


Figure 22 1 LSB reference pulse from myDAQ internal test signal

Table 3: Results from experiments with myDAQ DAQ system. (DAQ internally Generated signals)

V out p-p(volts)	Frequency (Hz)	Slew rate (kV/ms)	Settling time(us)	LSB(V)	Virtual relative accuracy		Estimated relative accuracy	Comment
					VOLT	LSB		
10	100	0.0276582	12.72	0.00031	0.09047	147.214286	0.557667104	Varying frequency
10	300	0.11524	4.024	0.00031	0.09047	147.214286	0.557667104	
10	500	0.1109833	3.18	0.00031	0.09047	147.214286	0.557667104	
10	1000	0.2203497	1.223	0.00031	0.09047	147.214286	0.557667104	
10	3000	0.9359199	0.3028	0.00031	0.09047	147.214286	0.557667104	
10	10000	3.4048781	0.1005	0.00031	0.09047	147.214286	0.557667104	
10	15000	1.7735849	0.07571	0.00031	0.04518	73.017038	0.557667104	
8	20000	1.8117788	0.07495	0.00031	0.04518	73.017038	0.557667104	
10	25000	----	----	0.00031		----	0.557667104	
8	10000	1.8757738	0.1018	0.00031	0.04545	73.4593709	0.557667104	Varying maximum voltage
5	10000	1.9687228	0.103	0.00031	0.04532	73.2463958	0.557667104	
3	10000	0.6840525	0.0751	0.00031	0.01823	28.8656619	0.557667104	
1	10000	0.4175229	0.0751	0.00031	0.00905	13.8230668	0.557667104	Varying Frequency
1	1000	0.0111179	2.423	0.00031	0.00905	13.8230668	0.557667104	
10	100		12.72	0.00031	0.00032	-0.4757536	0.557667104	Highest Value
10	100		31.93	0.00031	0.00022	-0.6395806	0.557667104	Lowest Value
10	100		22.325	0.00031	0.00027	-0.5576671	0.557667104	Average
System Noise	Relative accuracy per data sheet			Settling time per datasheet		Slew rate per data sheet		
	Absolute accuracy .= 19.6 mV to 42.8 mV					Slew rate. 4 kV/ms		

4.3 Results from embedded DAQ systems

4.3.1 Results from the PIC18F97J94 which is interfaced to a DAC0800.

PIC 18F97J94 uses one of its 8 bit ports to supply the DAC0800 with saw tooth wave that is in a binary format. DAC 0800 translate each incoming input value to a corresponding analog value

An oscilloscope is connected to the output of the DAC0800 where it is used when determining slew rate, settling time and relative accuracy . Refer to attachment called Annexure III for a detailed schematic.

PIC18F97J94 microcontroller uses its internal program to create the saw tooth wave that we have mentioned. Please refer to Annexure I for the source code.

During this experiment; the waveforms illustrated by Figure 23 to Figure 25 were displayed on the oscilloscope screen when the DAC produced a signal of 100 Hz, 15 V peak to peak.

The waveforms were studied carefully by identifying the position where the highest and the least value of relative accuracy occurs. Figure 24 shows an area where the reference signal has that has the settling time of 15.97 μ s and a slew rate of 0.0574 kV /ms. From Figure 23, Figure 24 and Figure 25, estimated relative accuracy (V) = $[(286.2 \text{ mV} - 135.9 \text{ mV}) + (58.3 - 135.9 \text{ mV})] / 2 = 36.35 \text{ mV}$. This value translates to 0.329 LSB.

Table 4 gives a summary of all other measured parameters.

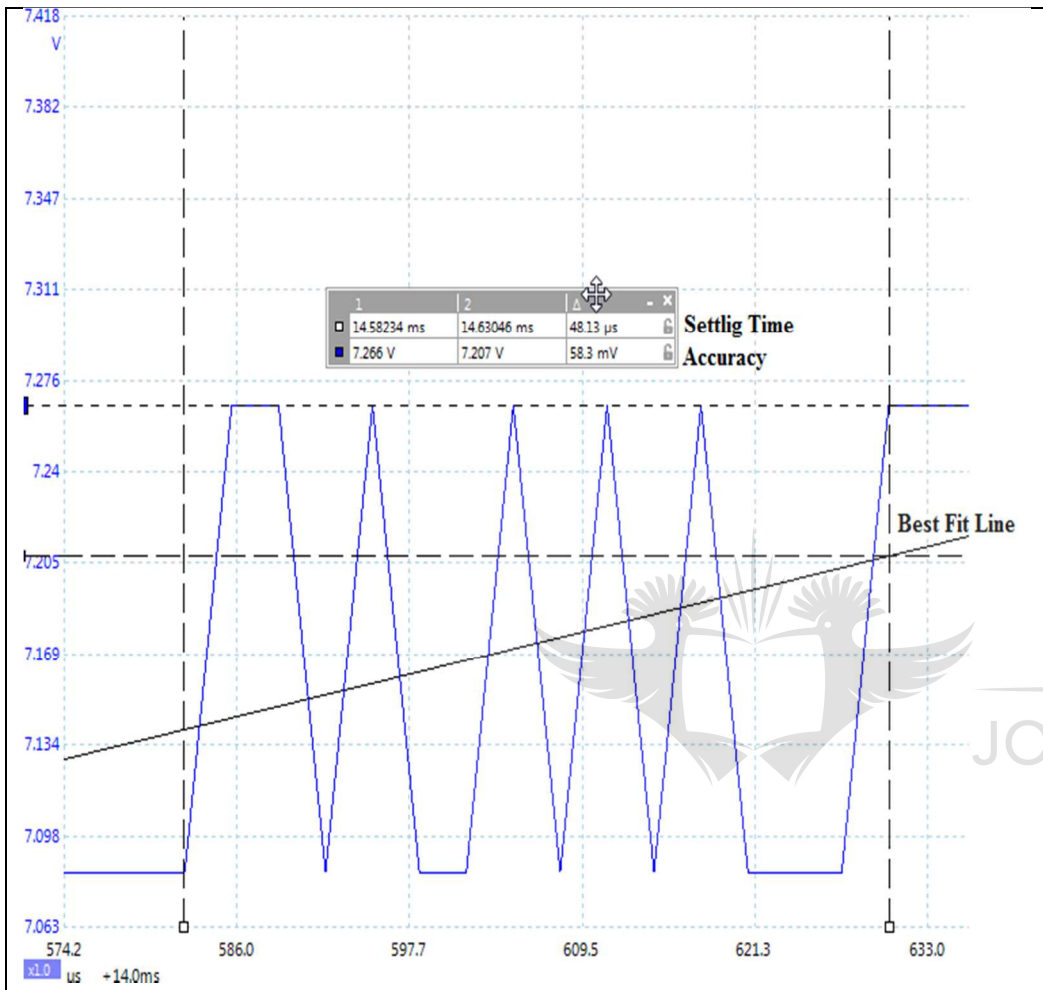


Figure 23 Pulse signal with the settling time of 48.13 μs

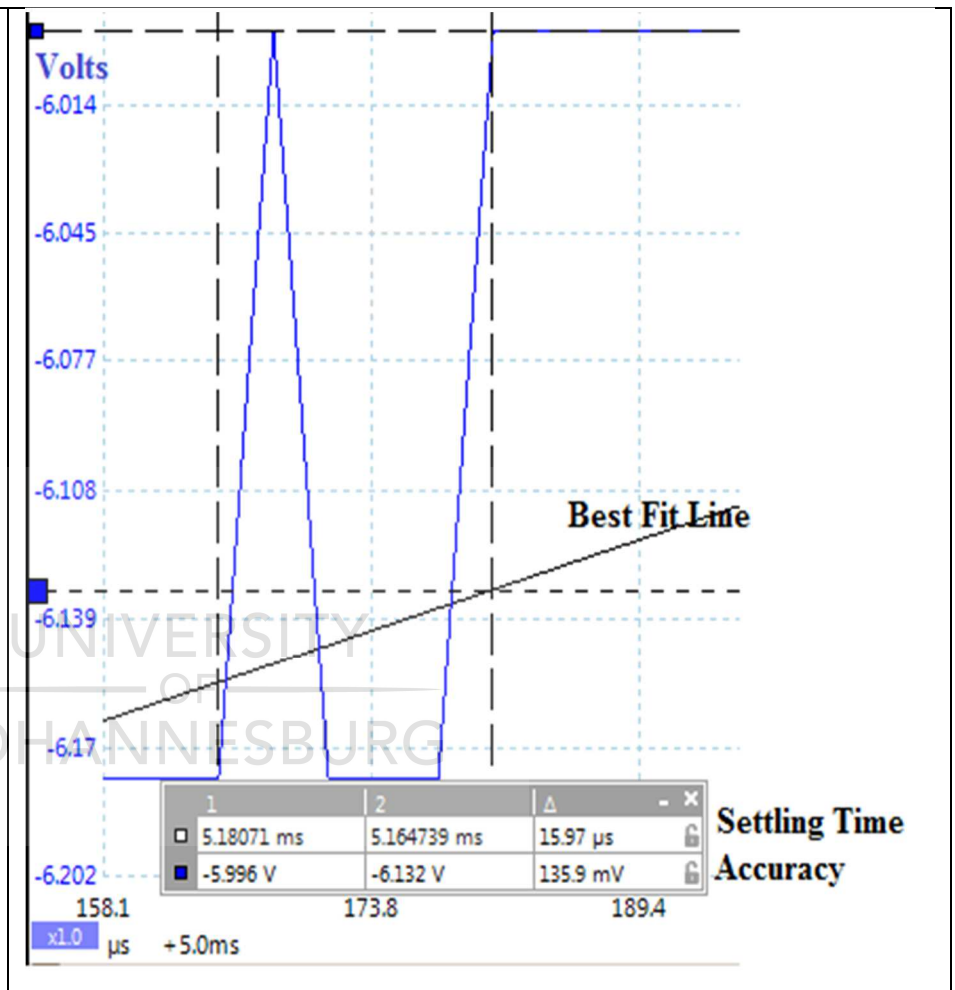


Figure 24 Reference pulse signal with the settling time of 15.97 μs

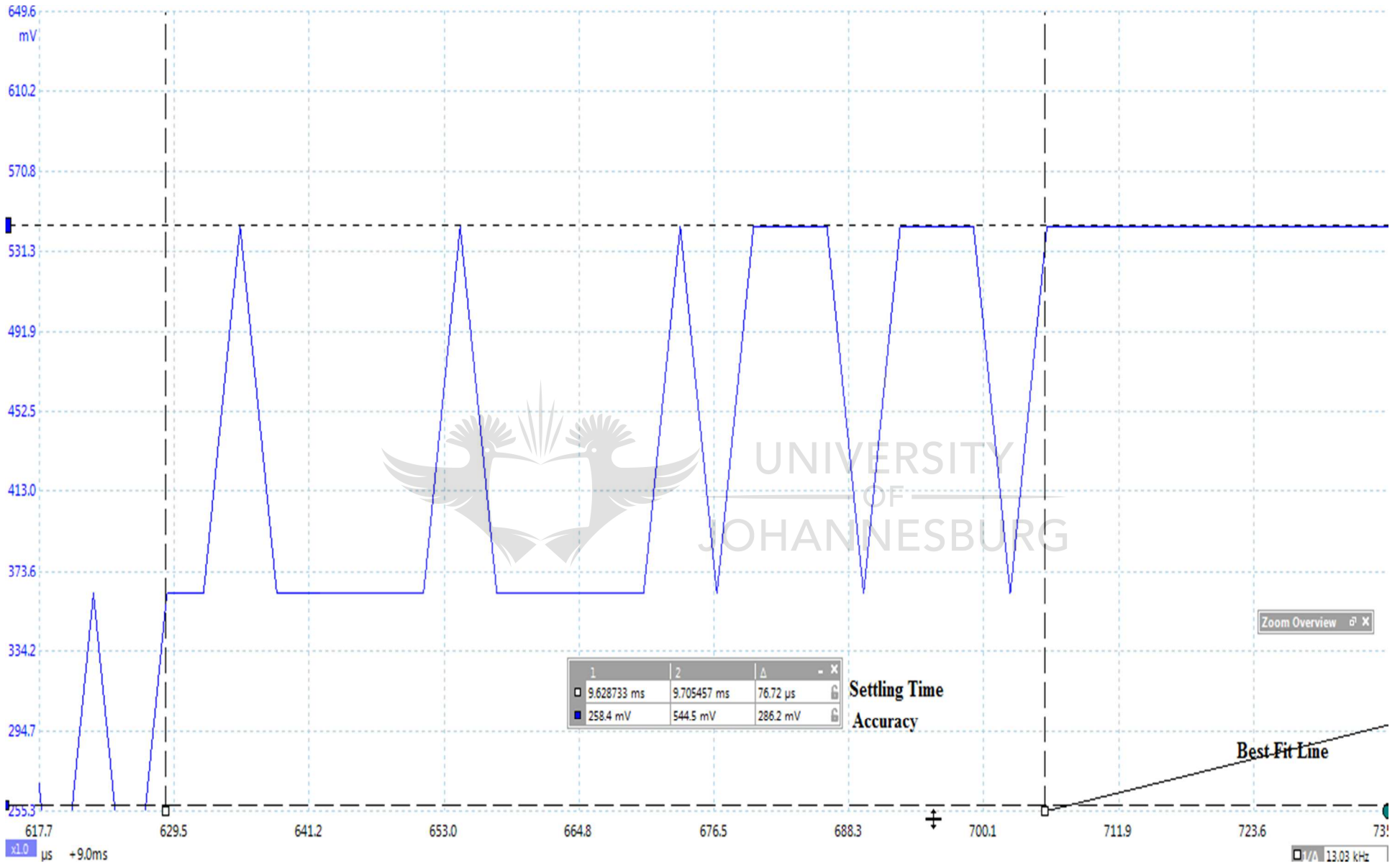


Figure 25 Pulse signal with the settling time of 76.72 μs

Table 4: Results from experiments with the PIC18F97J94 DAQ system

V out p-p (Volts)	Frequency (Hz)	Slew rate (Kv/ms)	Settling time(us)	LSB(V)	Relative accuracy		Estimated relative accuracy	comment
					Volt	LSB		
13.87	100	0.02673	19.25	0.0542	0.09036	0.16642066	0.171309963	Varying Frequency 0.2719 resolution 0.3803 resolution 0.4895 resolution 0.6527 resolution
13.87	300	0.115824	12.84	0.0542	0.09122	0.15848708	0.171309963	
13.87	500	0.2194998	5.621	0.0542	0.09123	0.15839483	0.171309963	
13.87	1000	0.2345318	2.385	0.0542	0.09062	0.16402214	0.171309963	
13.87	3000	0.938341	1.002	0.0542	0.09063	0.16392989	0.171309963	
13.87	10000	3.755906	0.3003	0.0542	0.09063	0.16392989	0.171309963	
13.87	15000	3.580544	0.275	0.0542	0.08982	0.17140221	0.171309963	
13.87	20000	3.748139	0.09928	0.0542	0.09063	0.16392989	0.171309963	
13.87	25000	3.4871104	0.07687	0.0542	0.09063	0.16392989	0.171309963	
10	8866	1.000552	0.4025	0.0542	0.12601	0.16246418	0.171309963	varying maximum voltage
5.028	9771	0.4379	0.1029	0.0542	0.17066	0.57430978	0.171309963	
3.082	9771	1.62644	0.2531	0.0542	0.04487	0.58607011	0.171309963	
1.38	10650	0.71784	0.07621	0.0542			0.171309963	varying frequency
1.38	1003	0.005139	10.61	0.0542			0.171309963	
13.87	100	0.02673	38.46	0.0542	0.17956	0.65645756	0.171309963	Highest value
13.87	100		19.25	0.0542	0.0001	-0.9990775	0.171309963	Lowest value
13.87	100		28.855	0.0542	0.08983	-0.17131	0.171309963	Average
Measured System Noise (peak to peak)			Relative accuracy per data sheet		Settling time per datasheet		Slew rate per data sheet	
DAC-0800		AD565	DAC-0800	AD565	DAC-0800	AD565		
60.47 mV			0.19%	±0.25	0.15 μs	5mA/ μs	8 mA/ms	

4.3.2 Results from the PIC18F45K20 which is interfaced to a DAC0800

PIC18F45k20 is programmed to generate saw tooth wave which is released by one of its output ports to the 8 bit digital to analog converter (DAC). The role of the DAC is to translate binary input wave coming from the PIC port onto an analog signal.

An oscilloscope that is connected at the output of the DAC is used when monitoring slew rate, settling time, relative accuracy and system noise that are produced by this DAQ system. Annexure IV is a detailed schematic that illustrates the PIC18F45k20 embedded DAQ system. The source code is included in Annexure II.

During this experiment; the waveform illustrated by Figure 26 was displayed on the oscilloscope. In this instance the microcontroller produces 100 Hz saw tooth wave that has peak to peak amplitude of about 15 V. The waveform was studied carefully by identifying the positions where the highest and the least values of settling time, slew rate and relative accuracy occur. Figure 26 shows an area where the settling time is $25.53\mu\text{s}$, slew rate equals to 0.0147 kV/ ms and virtual relative accuracy is $35.54\text{ mV} = 0.344\text{ LSB}$. All other results can be read from Table 5.



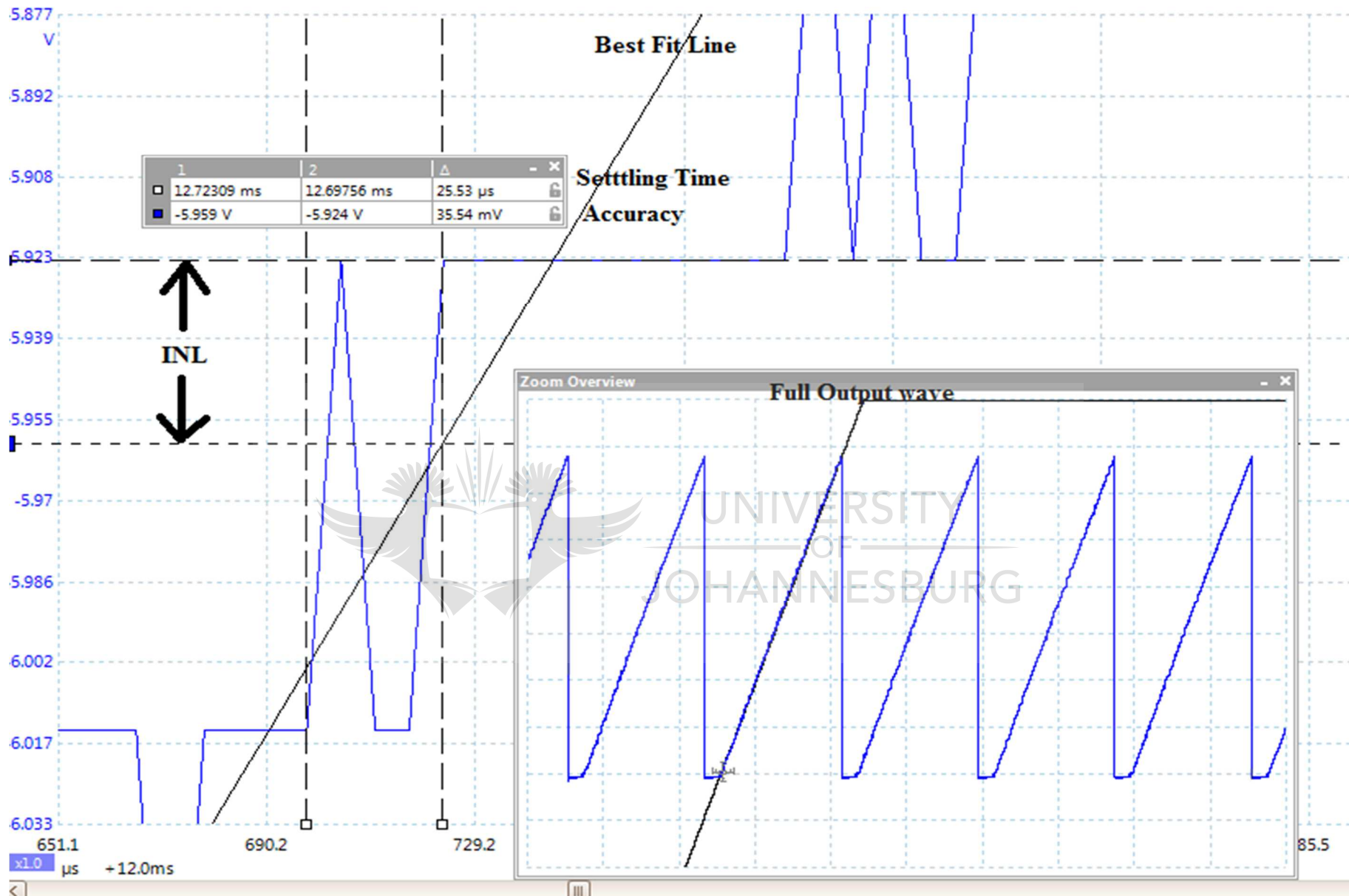


Figure 26 Pulse for measurements on PIC18F45K20

Table 5: Results from experiments with the PIC18F45K20 DAQ system

V ref (Volts)	Frequency (Hz)	Slew rate(kV/ms)	Settling time (us)	LSB (V)	Virtual Relative accuracy		Estimated	comment
					Volts	LSB		
13.87	100	0.0135935	19.38	0.05418	0.09054	0.16445183	0.994647471	varying Frequency 0.272 V resolution 0.979 V resolution 1.469 V resolution 1.741 V resolution 2.556 V resolution
13.87	300	0.05444	2.432	0.05418	0.09054	0.16445183	0.994647471	
13.87	451	0.130461	2.543	0.05418	0.09054	0.16445183	0.994647471	
13.87	812	0.11597	2.381	0.05418	0.09036	0.16611296	0.994647471	
13.87	3128	0.112455	0.8053	0.05418	0.09036	0.16611296	0.994647471	
13.87	9963	1.00033	0.9024	0.05418	0.09036	0.16611296	0.994647471	
13.87	15000	3.74008	0.1744	0.05418	0.09036	0.16611296	0.994647471	
13.87	20000	3.266811	0.0798	0.05418	0.0909	0.16112957	0.994647471	
13.87	25000	1.22229	0.09993	0.05418			0.994647471	
10	10900	3.95448	0.4025	0.05418	0.09036	0.16611296	0.994647471	Varying maximum Voltage
5.13	10120	0.4379	0.05078	0.05418	0.04532	0.58176449	0.994647471	
3.082	9771	1.8782	0.2531	0.05418	0.04505	0.58425618	0.994647471	
1.115	8094	0.32613	0.07631	0.05418	0.00909	0.91614987	0.994647471	Varying Frequency
1.048	1221	0.005139	7.555	0.05418	0.00909	0.91614987	0.994647471	
13.87	100		45.96	0.05418	0.0008	-0.9926172	0.994647471	Highest Value
13.87	100		19.38	0.05418	0.00036	-0.9966777	0.994647471	Lowest Value
13.87	100		32.67	0.05418	0.00058	-0.9946475	0.994647471	Average
Measured system noise (peak to peak)		Relative accuracy per data sheet		Settling time per datasheet		Slew rate per data sheet		
DAC-0800	AD565	DAC-0800	AD565	DAC-0800	AD565	DAC-0800	AD565	
43.72 mV (p-p)		0.19%	±0.25	0.15 μs	0.5 μs	8 mA/ms	5mA/ μs	

Chapter 5

Findings and discussions.

5.1 Introduction

In this chapter, detailed results obtained in chapter four are analysed. Graphs, diagrams and tables will be used to aid with this analysis. At the end of this analysis all the evaluated DAS will be compared on their performance. To conclude the findings, the reasons why some DAS perform better than the others are explained.

5.2 conventional DAQ systems

Two types of DAQ cards were selected to be used on the evaluation of conventional DAQ systems, i.e. myRIO and myDAQ. Note that the myRIO DAQ card can also be configured to work as an embedded DAS for applications other than this one. The choice of these two cards was based on performance range, cost and availability of resources such as software tools.

Of the four DAS used, myDAQ created the best performing system. Data sheets indicate that myDAQ has good resolution and better settling times. Again this device was designed solely for the purpose of acquiring signals.

It will be much convenient to start the discussions of our findings by looking at myDAQ; by so doing, we will create a better reference for the other three.

5.2.1 myDAQ based data acquisition system

Table 2 and Figure 27 illustrate how the values of slew rates, settling times and relative accuracies of myDAQ are affected by changes in frequency. A closer look at the curves on Figure 27 will also reveal the stability of the system with respect to frequency changes.

For a frequency ranging from 0 to 25 kHz this DAS has less relative accuracy related errors, good settling time and good slew rate. At frequencies above 500 Hz the DAS is seen to have very stable in performance as it keeps a constant value of virtual relative accuracy, settling time and slew rate.

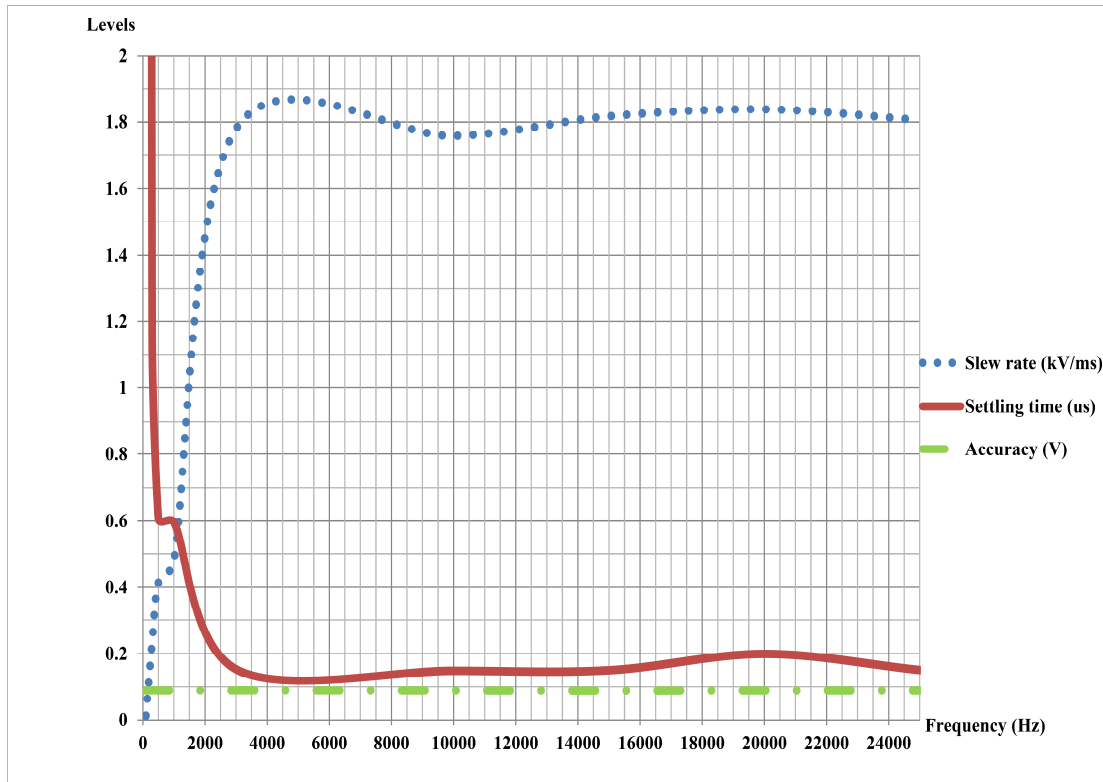


Figure 27 myDAQ performance over the frequency domain

The response of this DAS can also be studied over a voltage domain as illustrated by the Figure 28.

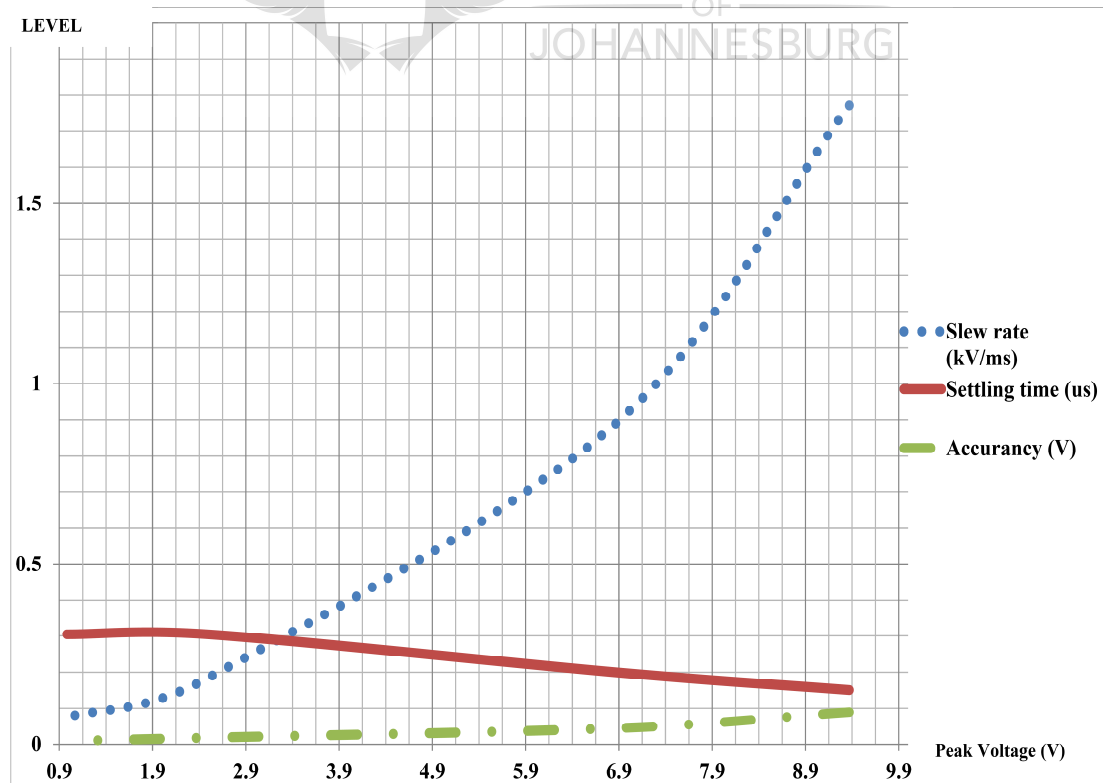


Figure 28 myDAQ performances over voltage domain

The accuracy and settling time of this device are less affected by changes in voltage as it is illustrated on Figure 28. The only concern is the dropping slew rate on low voltage signals. This is because a less amount of voltage has to be divided by high values of rise times.

Another parameter that has to be taken into consideration is the system noise, more especially when dealing with small signals.

Figure 29 is a representation of a noise signal produced by the output of myDAQ data acquisition system.

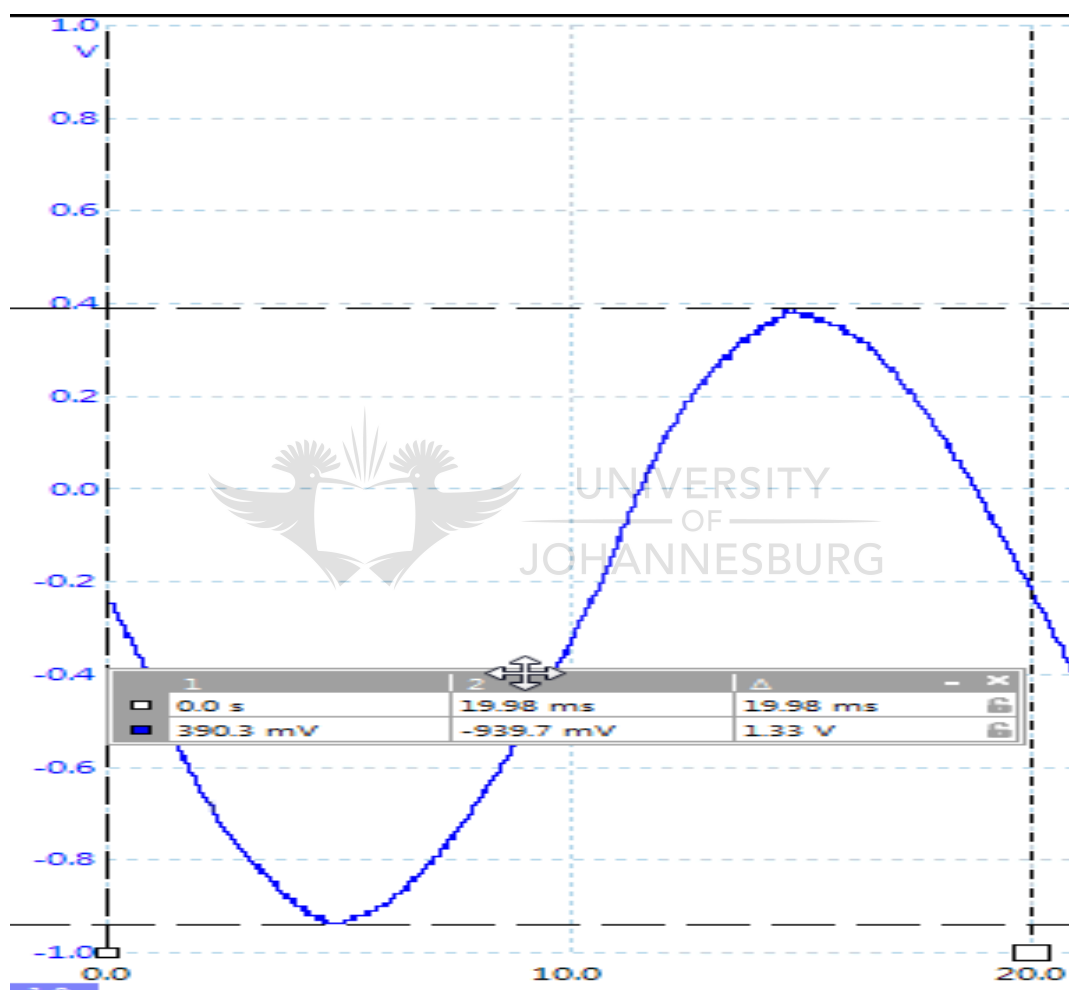


Figure 29 myDAQ Noise figure

Figure 29 illustrates that a huge mains noise figure is produced by this DAQ system. This conclusion is based on a 20 ms period. Any transformer equipment close to this unit will therefore create these kinds of interferences.

5.2.2 myRIO based data acquisition system

Figure 30 illustrates how the performance of myRIO DAS is affected by changes in frequency.

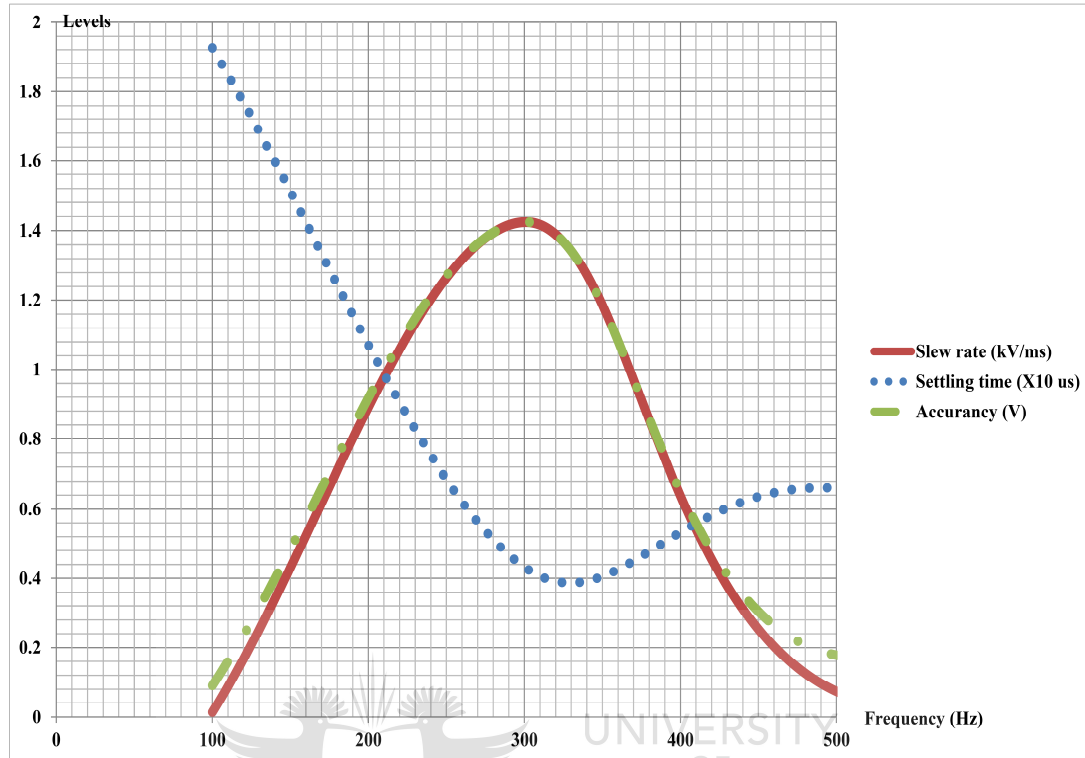


Figure 30 myRIO performances over the frequency domain

With this device, you can only get valid values at a frequency range between 100 Hz and 500 Hz. The graphs in Figure 30 illustrates that our parameters of interest are very unstable, they fluctuate with changes in frequency. This DAS cannot support very high frequencies; Values can only be read over a narrow band. Since the values used to plot graphs of Figure 30 were read over a narrow bandwidth, the shapes for these graphs appear to have sudden changes.

The response of this DAS can also be studied over a voltage domain as illustrated by the Figure 31.

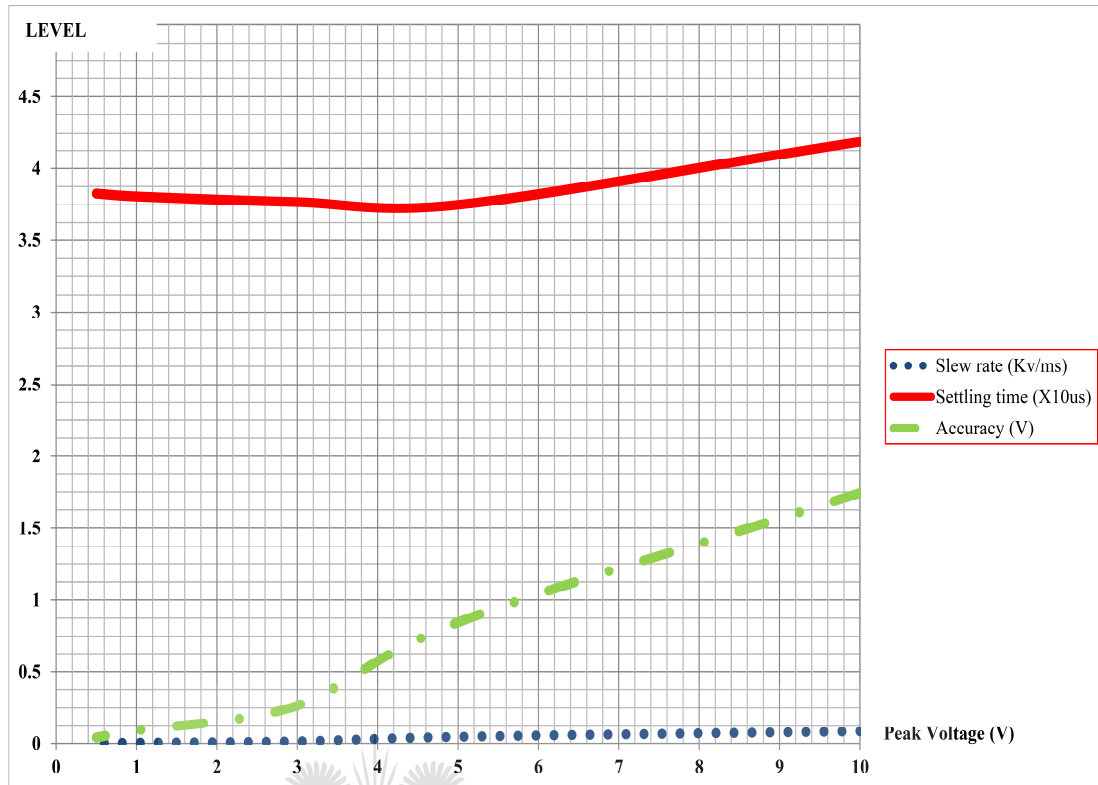


Figure 31 myRIO performance over the voltage domain

When compared to frequency changes, voltage changes seem not to affect the performance of myRIO DAS to a larger extent. However relative accuracy is seen to be rising slightly with increasing voltage.

Another parameter that was mentioned in section 3.4.4 is system noise. Noise was measured according to the methodology described in Chapter 3; Figure 32 shows the output of myRIO DAS when the system noise is measured by using the oscilloscope.

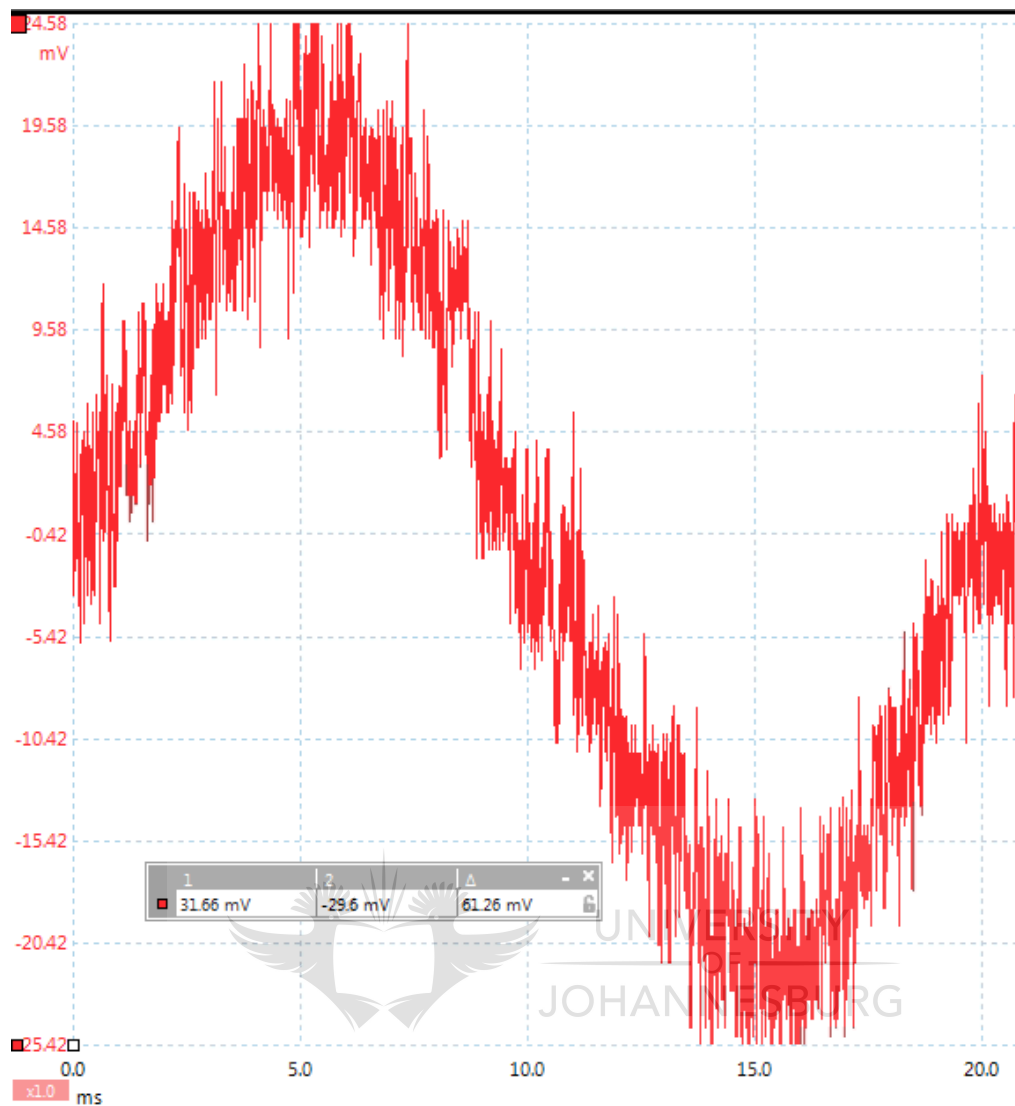


Figure 32 myRIO Noise figure

From the waveform illustrated by Figure 32, a system noise of 61.26 mV peak to peak can be noticed. The Major component of this noise figure is the mains input voltage since its period is 20 ms which translate to 50 Hz.

5.3 Embedded DAQ systems

Embedded DAQ systems were constructed by interfacing the PIC microcontrollers with either the 12 bit DAC AD565 or 8 bit DAC0800. The choice is based on the available resources, performance and price. We found the PIC18F45K20 and PIC18F97J94 microcontrollers to be much more suitable for this task. Note that this two are referred to as embedded systems since all the controlling software resides within the microcontrollers and no computer interfacing is necessary during operations. Of all DAS, PIC18F97J94 created the second best performing DAQ system after myDAQ. Data sheets confirm the PIC18F97J94 to be a faster controller.

5.3.1 PIC18F97J94 based DAQ system

Table 4 and Figure 33 illustrate how the performance of PIC18F97J94 DAS is affected by changes in frequency. On the curves represented by Figure 33, one will also visualize the stability of this DAS with respect to frequency variations.

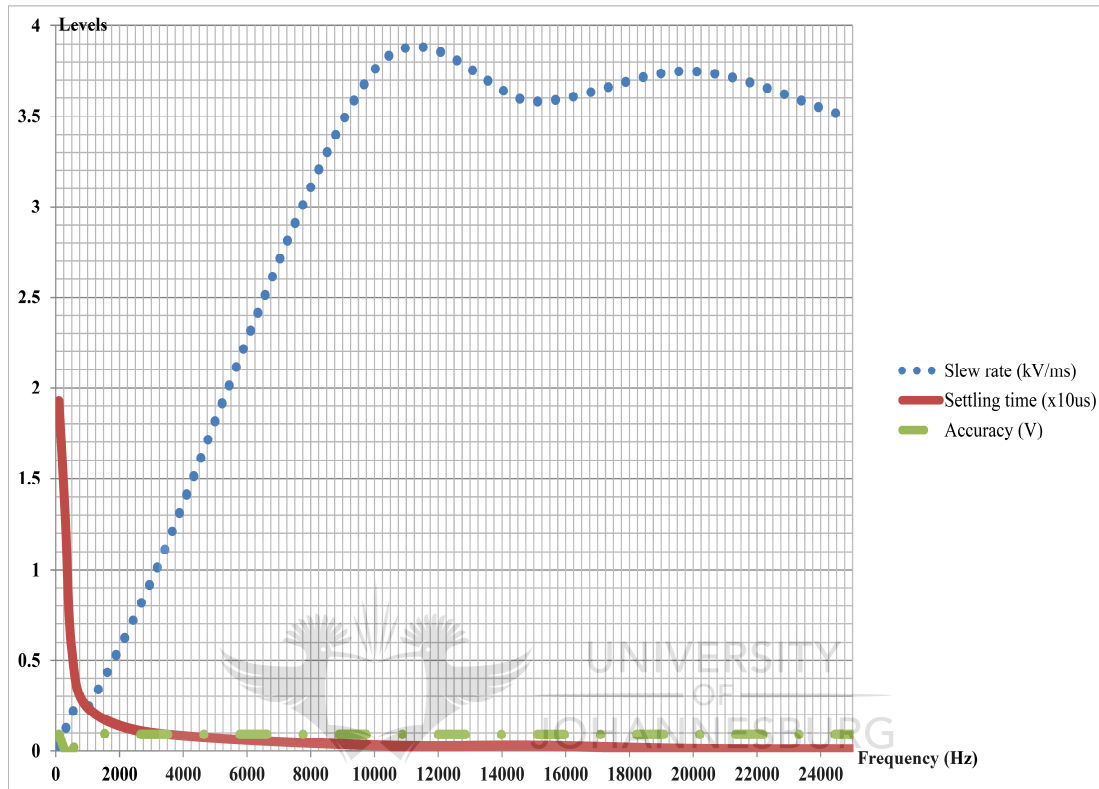


Figure 33 PIC18F97J94 performance over the frequency domain

At frequency between 0 and 25 kHz the DAS gives less relative accuracy related errors, at frequencies higher than 500 Hz; the settling time is very low whilst the slew rate increases rapidly until it reaches saturation at a frequency of about 10 kHz. Settling time fluctuates by ± 0.5 at the top; these are read errors influenced by positioning of cursors during measurement. The results illustrate how fast and stable the DAS is. The upper frequency is limited by the clock speed of the selected micro controller. The performance of this DQQ system is closely aligned to the one that was given by myDAQ. The response of this DAS can also be studied over the voltage domain as illustrated by Figure 34.

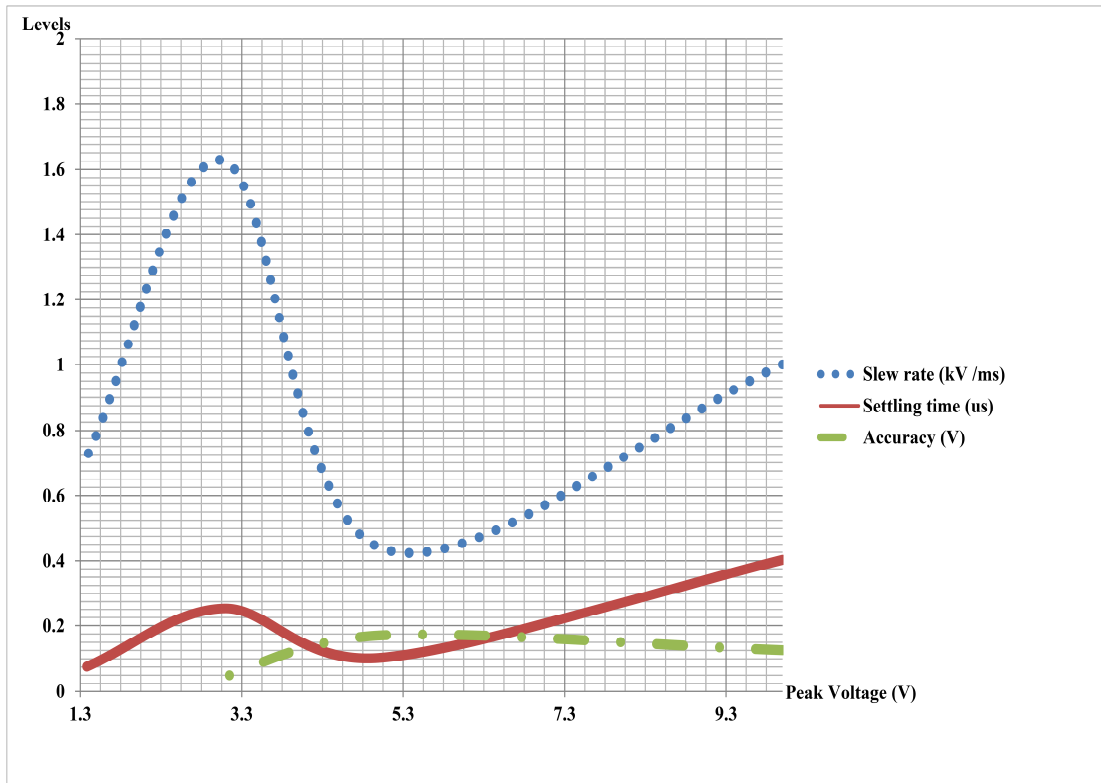


Figure 34 PIC18F97J94 performance over the voltage domain

The accuracy and settling time of this device are less affected by changes in voltage as it can be seen on Figure 34. The only concern is the unstable slew rate given by low voltage signals. The ratio of voltage to change in time becomes less since the signal voltage amplitude is very less. These responses almost similar to that given by my DAQ.

The discussion is continued by looking at the system noise, refer to Figure 35

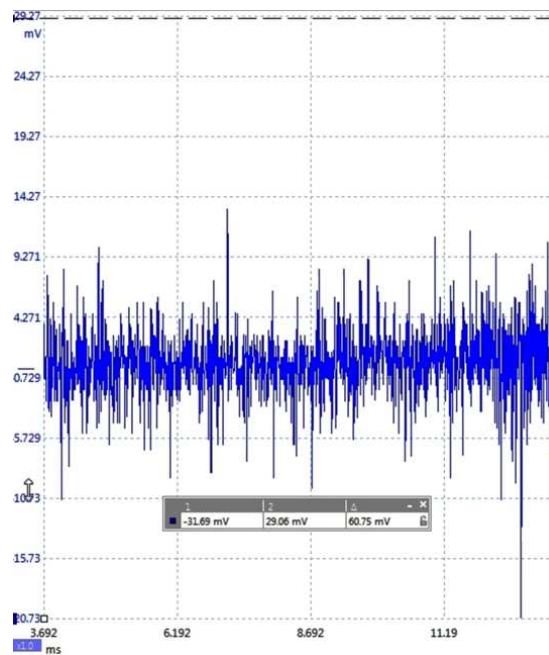


Figure 35 PIC18F97J94 Noise figure

Waveform illustrated by Figure 35 illustrate that the PIC18F97J94 DAS has a noise figure of 60.7 mV peak to peak. The development board of this controller is fitted with peripherals such as LCD and Microcontroller board. These additional components will play a major role to the overall system noise.

5.3.2 PIC18F45k20 based DAQ system

Table 5 and Figure 36 below illustrate how performance of the PIC18F97J94 DAS is affected by changes in frequency.

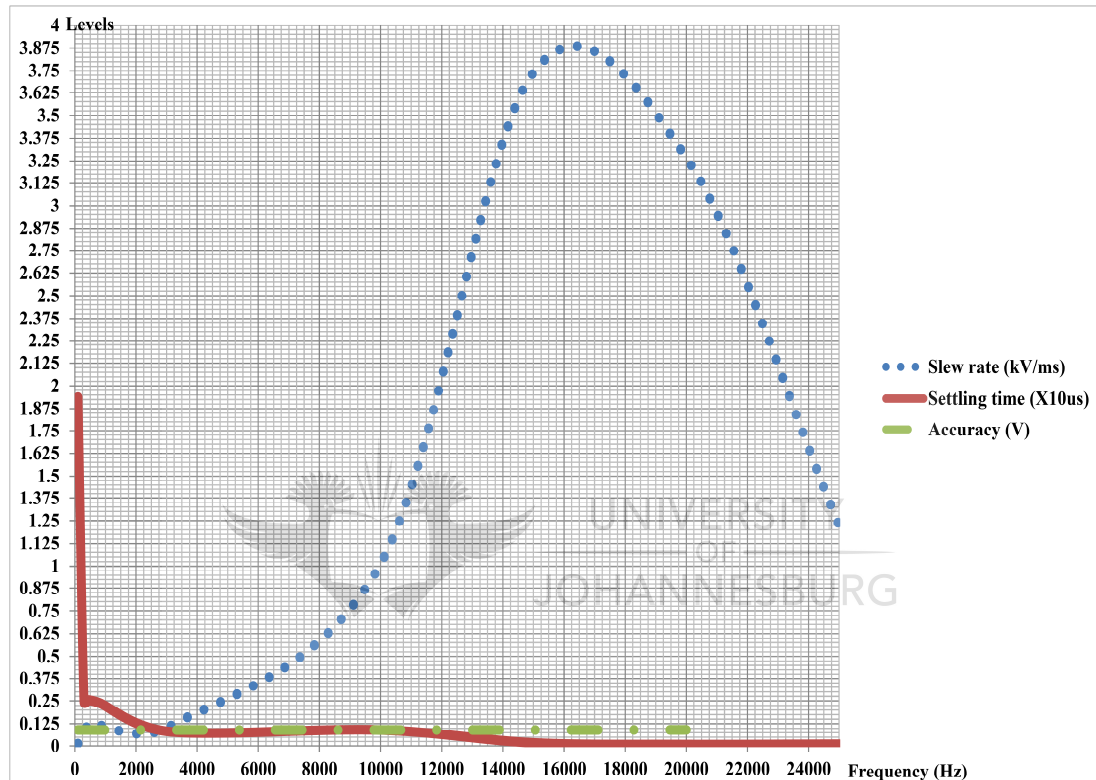


Figure 36 PIC18F45K20 performances over the frequency domain

For frequency between 0 and 20 kHz the DAS gives less relative accuracy related errors, and the DAQ system's performance is stable with respect to changes in frequency. However a slew rate graph clearly demonstrates to us that this parameter is never stable over wide range frequencies.

The data sheets do confirm performance of PIC18F45k20 to be poorer when compared to that of the PIC18F97J94. These results are therefore on par with the information supplied by respective data sheets in terms of performance.

The response of this DAS can also be studied over a voltage domain as illustrated by the Figure 37.

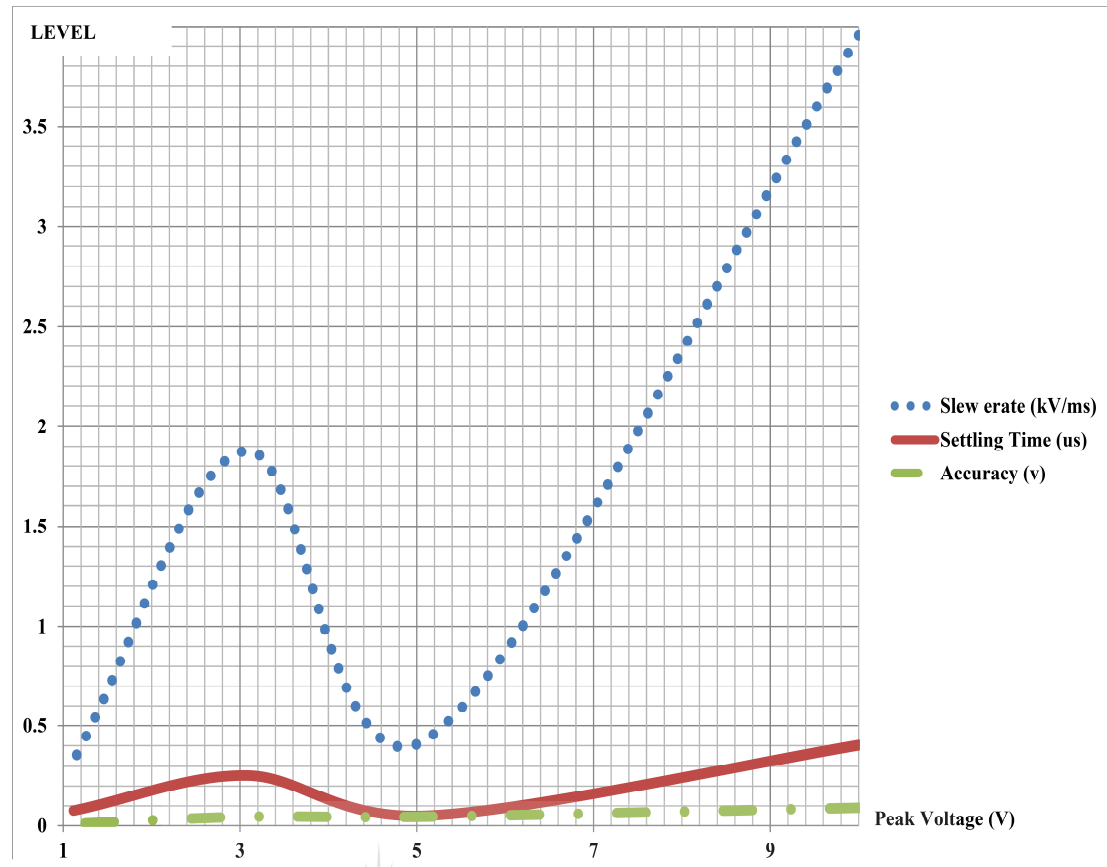


Figure 37 PIC18F45K20 performance over voltage domain

Similar to the previous curves, slew rate is found to be unstable. However in this instance, slew rate is found to fluctuate with voltage changes.

Figure 38 below illustrates the output noise given by PIC18F45k20 Microcontroller.

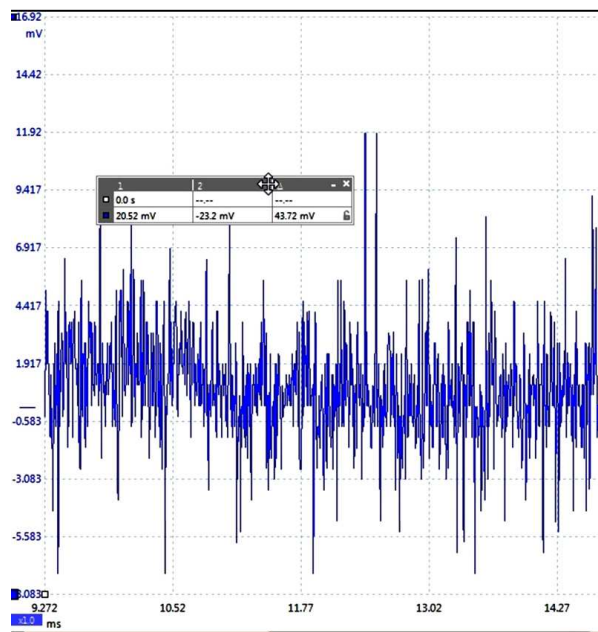


Figure 38 PIC18F45K20 Noise figure

Figure 38 shows that this DAS has a noise of 43.72 mV peak to peak. It should be remembered that overall noise depends on the circuitry used and not only on the DAC or Microcontroller.

5.4 Conventional DAQ system vs Embedded DAQ system

In this section, myDAQ based DAS is compared to PIC18F97J94 based DAQ system. Figure 39 shows how these two DAS respond to frequency changes.

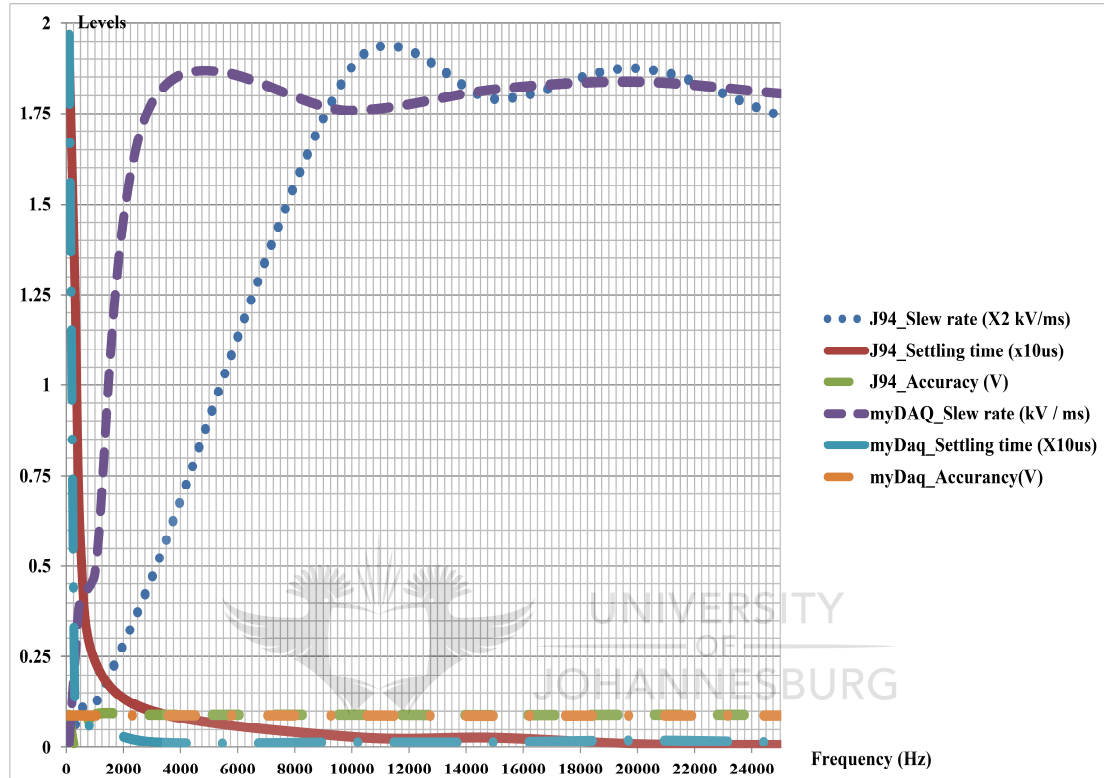


Figure 39 Conventional vs embedded DAS on the frequency domain

The two DAS have closely related responses to changes in frequency. Amongst other slight differences is that the slew rate of PIC18F97J94 is seen to be twice as much as that of myDAQ over a wide range of frequencies. Also, the accuracy of myDAQ is more stable when compared to that of the PIC18F97J94 system.

These two systems can also be compared over a voltage domain as illustrated by Figure 40

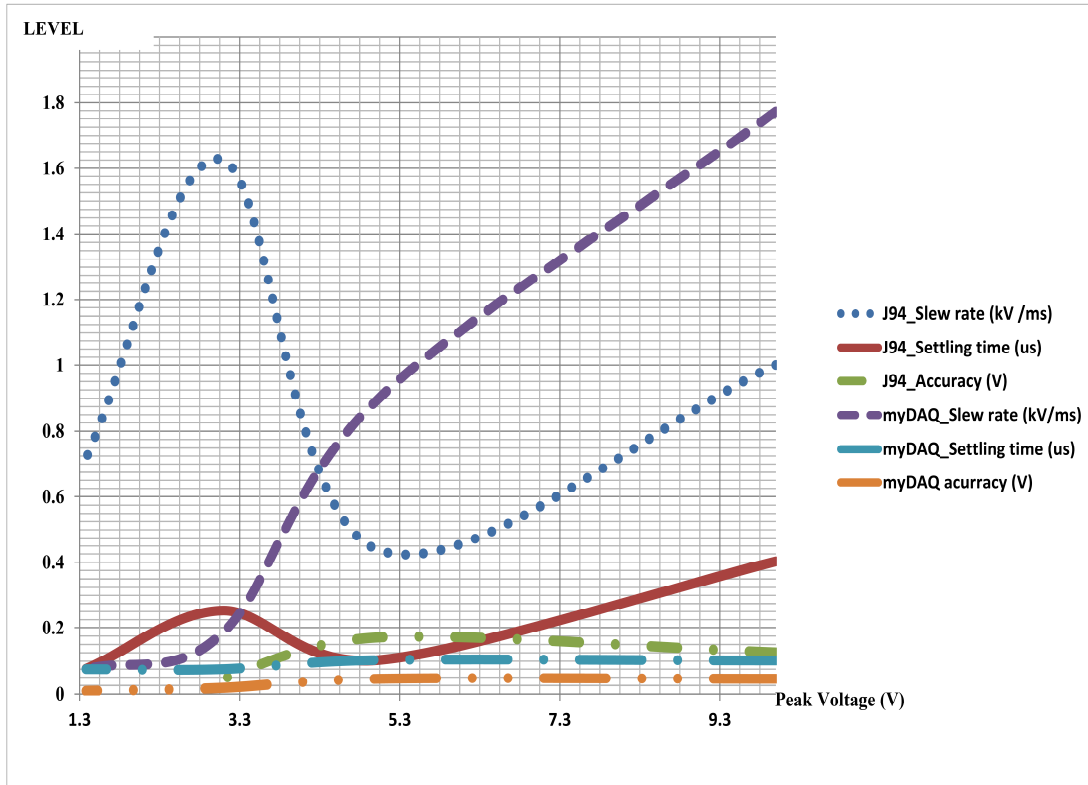
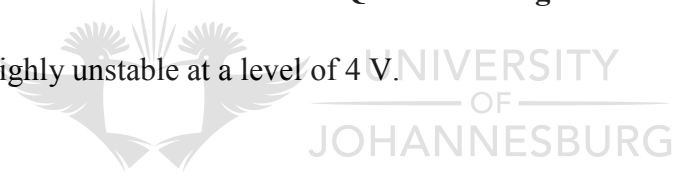


Figure 40 Conventional vs embedded DAQ on the voltage domain

The signals are highly unstable at a level of 4 V.



5.5 Table 6: Average values on the performances of all tested DAQ systems

Average parameter value (Unit)	Conventional DAQ System			Embedded DAQ system	
	myRIO	myDAQ		PIC18F97J94	PIC18F45k20
Frequency domain (100 Hz – 25 kHz)	External signals	External signals	Internal signals	Internal signals	Internal signals
Settling time (μs)	8.148	4.649938	2.71262	4.649939	3.199759
Slew rate (kV/ms)	0.37775	1.126789	1.050049	1.789625	1.072937
Virtual relative accuracy (V)	0.622925	0.08881	0.079148	0.090474	0.090495
Estimated relative accuracy (LSB)	8.380123	0.115334	0.557667	0.17131	0.994648
Voltage domain (1 -10 V p-p)					
Settling time (μs)	3.096	0.84886	0.5556	2.288942	1.667538
Slew rate (kV/ms)	0.05239	0.587721	0.991437	0.7575742	1.32037
Virtual relative accuracy (V)	0.018	0.00054	0.025419	0.113845	0.03978
Estimated relative accuracy (LSB)	8.380123	0.115334	0.557667	0.17131	0.994648
System noise (Peak to Peak)	61.28 mV	1.33 V		60.75 mV	43.72 mV

Table 6 above summarizes average results for the performances of both conventional and embedded DAQ systems. Settling time ranges from 3.2 to 8.2 μs , Slew rate ranges from 0.4 to 1.8 kV /ms and estimated relative accuracy 0.1 to 8 LSB. myDAQ provides good performance followed by PIC18F97J94 DAS. It can also be seen that myRIO has poor performance when compared to the other three DAQ systems.

5.5 Findings

- It was found that the resolution of a DAS and its processing speed influences its output performance.
- Expensive DAQ cards like myRIO will not necessarily give better acquisition performance, but rather provide delicate features that are unrelated to acquisition speeds.
- Lower voltages will bring instability to the DAQ system; therefore signal conditioning will be very crucial.
- Embedded DAQ system that are built from high speed microcontrollers can be utilized to replace conventional DAQ system where cost has to be kept low but better performance is still required.
- Table 7 summarizes the performance of myRIO, PIC18F45K20, PIC 18F97J94 and myDAQ in the order ranging from worst to best.

Table 7: Performance indicators based on this research

DAQ system	Slew rate	Settling time	Accuracy	Noise
myRIO	Very unstable & very bad	Very unstable & very bad	Very unstable & very bad	61.28 mV
PIC18F45K20	Unstable & bad	Unstable & very good	Very stable & good	43.72 mV
PIC18F97J94	Stable & very good	Stable & very good	Stable & Very good	60.75 mV
myDAQ	Very stable / very good	Very stable / very good	Very stable /very good	1.33V

Chapter 6

Conclusions and Future Research

6.1 Conclusions

In this research we compared conventional data acquisition system (DAS) with the embedded data acquisition systems. The performance specifications of 4 different types of DAQ cards are drawn up with special emphasis made on the following parameters: Slew rate, settling time, relative accuracy and system noise. These parameters are taken from 2 conventional DAS and then compared to those taken from 2 embedded data acquisition systems under the same electrical conditions. The embedded DAQ system's hardware was built using the PIC Microcontroller interfaced to the Digital to Analog Convertors (DAC). MPLAB C18 is used to create a program which communicates with the embedded DAQ system, to transmit generated signals. National Instrument's LabVIEW is used to create a program which communicates with the conventional DAQ system, to acquire external generated signals and retransmit the signals. In most cases the performance of conventional and embedded are close, but one of the embedded DAS seem to be unstable at high frequencies.

The results in chapters 4 and 5 demonstrated that the conventional DAQ systems have the performance that are similar to those of embedded DAQ systems. These results also made it clear that in all DAS, values of slew rates, settling time, relative accuracy and system noise are less affected by volage and frequency changes of the produced output.

6.2 Future research on data acquisition system

This research was very close to revealing techniques that can be used to directly measure slew rate, settling time and relative accuracy of a DAQ system. In future, research can be conducted to find simple techniques to directly measure slew rate, settling time and relative accuracy.

DAQ systems are building blocks of instruments such as computer based oscilloscopes, signal generators, etc. Most of these instruments can not be shared over a computer network. This research can be taken forward onto cheap remote Labs that use embedded DAQ systems.

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ANNEXURES



ANNEXURE I (PIC18F97J94 Source code)

```

/*****
File name: PIC18F97J94_Saw tooth_8bit__DAC0800
This MPLABC c code is used with a PIC18F97J94 to create an 8 bit Saw tooth wave
Hardware:
PIC18F97J94 8 bit Microcontroller
8bit DAC0800 8 bit to 8 bit Digital to analog converter
Software:
Microchip's MPLAB C32 and MPLAB IDE v8.92
*****/

```

```

/*****CONFIGURATION BITS *****/
#pragma config STVREN = ON // Stack overflow reset
#pragma config XINST = OFF // Extended instruction set
#pragma config BOREN = ON // BOR Enabled
#pragma config BORV = 0 // BOR Set to "2.0V" nominal setting
#pragma config CP0 = OFF // Code protect disabled
#pragma config FOSC = FRCPLL // Firmware should also enable active clock tuning
#pragma config SOSCSSEL = DIG // SOSC circuit configured for crystal driver mode
#pragma config CLKOEN = OFF // Disable clock output on RA6
#pragma config IESO = OFF // Internal External (clock) Switchover
#pragma config PLLDIV = NODIV // 4 MHz input (from 8MHz FRC / 2)
#pragma config POSCMD = NONE // Primary osc disabled, using FRC
#pragma config FCKM = CSECMD // Fail safe clock monitor disabled
#pragma config WPDIS = WPDIS // Program memory not write protected
#pragma config WPCFG = WPCFGDIS // program memory not write protected
#pragma config IOL1WAY = OFF // IOLOCK can be set/cleared as needed
#pragma config LS48MHZ = SYSX2 // Low Speed USB clock divider
#pragma config WDTCLK = LPRC // WDT always uses INTOSC/LPRC oscillator
#pragma config WDTEN = ON // WDT disabled; SWDTEN can control WDT
#pragma config WINDIS = WDTSTD // Normal non-window mode WDT.
#pragma config VBTBOR = OFF // VBAT BOR disabled

```

```

/** INCLUDES *****/

```

```

#include "p18f97j94.h"
#include "delays.h"

```

```

/*****Frequency Tuning*****/

```

```

#define _13V_100Hz 20
#define _13V_300Hz 5
#define _13V_500Hz2
#define _13V_1000Hz 0

```

```

/*****RESOLUTION CHANGES*****/

```

```

#define _STEP_25kHz 12
#define _STEP_20kHz 9
#define _STEP_15kHz 7
#define _STEP_10kHz 5

```



```

/**DECLARATIONS and FUNCTIONS *****/
//LINDA is a function that receive an integer and then delays an execution of a code
//that follows its call
void LINDA (int count) //Delay
{
    int dex;
    for(dex = 0;dex< count; dex++)
        {Nop();}
}
void main (void)
{
while (1)
    {
    int count;
    TRISD=0b00000000; // PORTD is set to be output
    PORTD=0b00000000;
    for(count=1; count <256; count=count+1)
        {
        PORTD = count; // Write value
        LINDA (_13V_100Hz);
        }
    }
}

```



ANNEXURE II (PIC18F45K20 Source code)

```
/*  
*****
```

File name: PIC18F45K20_Saw tooth Wave 8bit_DAC0800

This MPLABC c code is used with a PIC18F45K20 to create an 8 bit Saw tooth wave

Hardware:

PIC18F45K20 8 bit Microcontroller
DAC0800 8 bit to 8 bit Digital to analog converter

Software:

Microchip's MPLAB C32 and MPLAB IDE v8.92

Functions: LINDA, controls the frequency based on received integer parameter;
returns null

```
*****/
```

```
/** INCLUDES *****/
```

```
#include "p18f45k20.h"
```

```
#include "delays.h"
```

```
/** DECLARATIONS *****/
```

```
/*Delay*/
```

```
#define _50Hz 94 //Low Speed Internal Oscillator
```

```
#define _100Hz 3
```

```
/*Adjust Resolution*/
```

```
#define STEP_3kHz 5
```

```
#define STEP_10kHz 18
```

```
#define STEP_15kHz 27
```

```
#define STEP_20kHz 32
```

```
#define STEP_25kHz 47
```

```
void Setup Clock()
```

```
{
```

```
//Enable PLL to multiply internal clock by 4. Select 16 MHz internal clock. Therefore  
16 * 4 = 64MHz CONFIG1Hbits.FOSC = 0b0110;
```

```
// OSCCONbits.IRCF0 = 1;
```

```
OSCCONbits.IRCF1 = 1;
```

```
OSCCONbits.IRCF2 = 1;
```

```
OSCCONbits.SCS1 = 1;
```

```
OSCTUNEbits.PLEN = 1;
```

```
OSCTUNEbits.INTSRC = 1;
```

```
OSCTUNEbits.TUN = 0b011111;
```

```
}
```

```
void LINDA(int count) //Delay
```

```
{
```

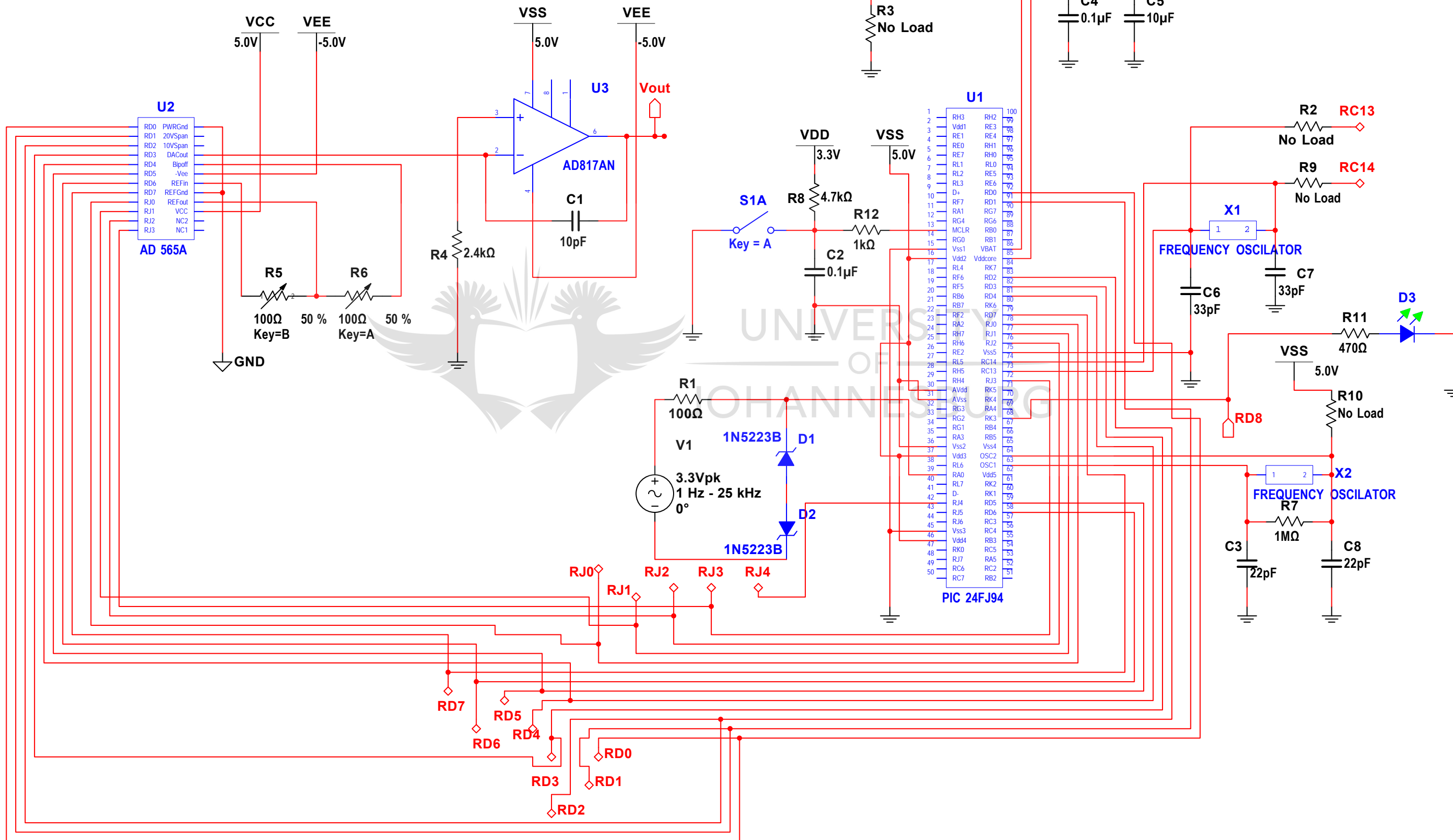
```
int dex;
```

```
    for(dex = 0; dex < count; dex++){  
    }  
void main (void)  
{  
  
    int count;  
    TRISD = 0b00000000; // PORTD is configured to be output  
    PORTD=0b00000000;  
    SetupClock();  
    while (1)  
    {  
        for (count =0; count<8; count++)  
        {  
            PORTD= count;    // Write count  
            LINDA (_100H z);  
  
        }  
    }  
}
```



ANNEXURE III (PIC18F97J94 DAS)

Title: Embedded DAQ using PIC97FJ94 and 12 bit AD565A		
Size: A3	Document N: 1	Revision:
Date: 26/03/14	Sheet 1 of 1	



ANNEXURE IV (PIC18F45K20 DAS)

Title: Embedded DAQ using PIC18F45K20 and 8 bit DAC0800		
Size: A	Document N: 1	Revision:
Date: 24/03/14	Sheet 1 of 1	

