GUI Application for Measuring Instruments
Noise Measurement System

Usman Tariq

April 1, 2013

Abstract

The always growing demands on the electronics design of modern electron microscopes cause increased requirements to the measurement tasks in the electronics development of these systems. In this thesis, we report the findings of designing noise measurements setup in Carl-Zeiss, Oberkochen. The aim of this thesis was to explore the design setup for noise measurement and to provide an interface which help us analyze these measurements using C# and agilent multimeter. This was achieved by the construction and evaluation of a prototype for a noise measurement application. For this purpose Design Science Research (DSR) was conducted, situated in the domain of noise measurement research. The results consist of a set of design principles expressing key aspects needed to address when designing noise measurement functionality. The artifacts derived from the development and evaluation process each one constitutes an example of how to design for noise measurement functionality of this kind.

Keywords: Electron microscopes, Noise Measurements, Design Science, C#, Agilent.
Acknowledgements

I thank to Allah (God) Almighty the Creator of knowledge. I express my profound thanks to all my teachers, especially at the Department of Informatics and Media, for their advice and guidance throughout my studies. Special thanks to Anneli for always being helpful, to my supervisors Andreas Hamfelt, Edgar Fichter and Joerg fober for their supervision and providing me opportunity to work on this thesis.
1) Introduction:

H. James Harrington once said, Measurement is the first step that leads to control and eventually to improvement. If you can’t measure something, you can’t understand it. If you can’t understand it, you can’t control it. If you can’t control it, you can’t improve it (Terence A. Shimp, 2010).[1] Measurement plays an important role to test theories that are led by experiments. An experiment is a process that can lead to result and conclusion about the system. Measurement also provide capability to analyze the data for testing theories and performing controlled experiments.

The always growing demands on the electronics design of modern electron microscopes cause increased requirements to the measurement tasks in the electronics development of these systems. The goal of this thesis is come up with the working design for noise measurements and interface that connects the instruments to the GUI application. The analysis and conceptual design will yield a GUI - application (C++ / C#) for Microsoft Windows 7 platforms shall be developed that allows control and data acquisition with the following measuring instruments, Agilent 3458A precision DMM.

Modern electron microscopes have many high stability requirements, stable electron beam (via electron gun) generation and electromagnetic lenses voltage stability and are among the two which requires special consideration. The electron gun refers to the top region of the SEM that generates a beam of electrons. Two important parameters for any electron gun are the amount of current produced and the stability. The beam is most stable at the saturation point, the point for the optimal setting for the filament, at which maximum electron emission is achieved.[2]

In order to create good quality images, a constant beam current and energy is required. The electron micrograph is produced over a period of time, usually at a slow scan rate to achieve high quality in photographs. The electron micrograph contains information about the intensity values for the specimen. Poor quality image will be produced if there are changes put in the filament emission during the scan as brightness will vary across the image. It is therefore very important to achieve saturation.[2]

There are two lens sets used in most SEM’s. The condenser lens is at the top and the objective lens which is at the bottom. Each lens is designed to perform a different job. The condenser lens converges the cone of the electron beam to a spot below it. The objective lens also has some influence over the diameter of the spot size of the electron beam on the specimen surface. But the main role is in focusing the beam on to the sample. A focused beam produces a smaller spot on the surface than an under or over-focused beam. Voltage stability of these lenses is very important to focus the electron beam on the sample, an unstable voltage sources would result in defocused images.

This thesis covers the need for the measurement of current sources and to make sure that acceptable stability is achieved with noise ranges that do not hinder the stable generation of electron beam or current source for the two lenses. Among the task list above one major task is understanding of the instrument working, the DC current and DC Voltage measuring with high level of accuracy and digitizing modes.
1.1) Problem Relevance:
Secondary electron microscopes have high stability requirements and there is a need for stable current/voltage setting to be able to view an image which is not subjected to noise. Joel guide [3] to SEM mentions that different type of Image disturbances can be classified by the following expressions:
1) Images that are lacking sharpness and contrast
2) Images those are unstable
3) Images with poor quality in general
4) Images with noise
5) Images showing rough edges
6) Images that have unusual contrast
7) Images those are distorted or deformed.

There is a growing demand for design of modern electron microscopes which increases the requirement for measurement task in the development of these systems. Measurement task for noise is an important step in the design of an electron microscope. As SEM’s are very sensitive to noise and there are numerous factors which can hinder the quality of images, which are explained later in detail. There is need to measure these sources accurately so that can help us design an effective electron microscope design. For the current thesis we are interested in the noise readings for the primary source voltage, the electron gun, the two lenses namely being the objective and condenser lens.

The importance of primary voltage source, electron gun current stability and the amount of current that is provided to the two lenses is discussed in the later chapters. For desired image results it is very vital to understand the working of SEM in general and get a basic insight into the different part of it.

For the effectiveness of electron microscope, it needs to undergo some tests as to check the stability factors. Measuring for these factors manually via DMM is a tedious and time consuming process as there are some test that need to carried out for longer period of time repeatedly, usually the measurements that are slow can take 2-3 hours or more than a day in some cases. This suggests the imminent need for a software system for the measurements which helps the end user to easily carry out these tests without being there all the time. Agilent DMM 3458A which is primarily used this thesis for the measurement process has a library interface that makes it easy to communicate with the software system. The software system will aid in adjusting different states of the DMM and saving/reloading of states in form of XML file for later use. The software system will also produce result in CSV format which will be later analyzed via Matlab for possible noise occurrence.

One important step of this thesis will be to understand the sources of noise and using the principle techniques of signal processing in order to reduce the noise for high precision measurement. One such technique that is used is signal averaging. Signal averaging is a signal processing technique applied in the time domain, intended to increase the strength of a signal relative to noise that is obscuring it. “By averaging a set of replicate measurements, the signal-to-noise ratio, S/N, will be increased, ideally in proportion to the square root of the number of measurements” (wikipedia).[4] This would be utilized in the current thesis by using multiple multimeters for measuring on the same time stamps. We gather synchronous measurement data via the software part of noise measurement system and analyze the benefit and effect of reading synchronous data in our design.

1.2) Aim:
The aim of this thesis was to propose a design/technique and to develop system functionality in gathering noise measurements. To fulfill this aim, we designed and introduced IT artifacts using design science research as proposed by Hevner, et al., 2004. [5]
1.3) Research Questions:

Stability of electron microscope towards noise is vital in case of precise measurements. Although noise in the instrument can come from different sources, our focus for the current thesis lies in the domain of measuring the noise for electron gun, the two lenses and power supply and the input noise of the multimeter.

The first aim of this thesis is to answer the research questions:

*RQ1: How can we design a setup for noise measurement and what technique can be used to reduce noise that can be utilized with the current setup?*

The second research question supports the purpose to find out the possibility of noise reduction, using the technique to reduce noise as described above.

*RQ2: Using the measurement data, what will be the effect on RMS (Root mean square) using the noise reduction technique?*

Wikipedia defines information system (IS) as “The study that bridges business and computer science using the theoretical foundations of information and computation to study various business models and related algorithmic processes within a computer science discipline”. Information System aims to support operations, management and decision making. The term (IS) is used to refer the way an organization uses Information and communication technology (ICT) in which people interact with the technology in support of business processes needs.

In the current thesis I have tried to identify the user needs in terms of noise measurement system and a design system that enable us to do noise measurements. I have utilized concepts ranging over principles of electron microscopy, noise measurements and signal averaging to come up with artifact that bridges user needs/real world problem with computer science. By using the techniques I have designed and developed a system that help us the real world problem of noise measurement and support the user needs in that regard.

1.4) Delimitations:

This study has several delimitations. It is delimit to the instrument in use. In the current application we did the design setup and noise measurement gathering via Agilent 3458A precision DMM. For the Application to work and take readings, it has to be made certain that the instrument setup is working correctly. There is one other Limitation of data rate of the noise measurements that can be read accurately. The current application does not allow a date rate more than 1000 readings/s from a single instrument, going across this limit hinders the synchronous results. Also the noise sources that are to be considered are from the primary voltage source, electron gun, the two lenses and the input of multimeter. Any other noise source measurement are out of the scope of this thesis.
2) Research Methodology:

The understanding of problem and knowledge about the domain are two factors that are very important for any research. Theoretic understanding about the underlying facts helps in weighing information for creating and testing artifacts is vital in achieving the research goals.

As mentioned by Alan R. Hevner in his article MIS Quarterly (Design Science in Information Systems Research) [5], two paradigms characterize much of the research in the Information Systems discipline: behavioral science and design science. The former paradigm seeks to develop and verify theories that explain or forecast human or organizational behavior. The later paradigm searches for extension of the boundaries of human and organizational capabilities by creating new and innovative artifacts. Design science thus emphasizes on the creation of an artifact rather than just describing the theory. Hevner suggests a research framework for IS in order to achieve a good understanding of information systems research and by developing a set of guidelines for conducting and evaluating good design-science research.

![Figure 2.1: Hevner et al (2004), Design science in IS research, MIS Quarterly, vol. 28, no. 1, pp 75-105.](image)

In Figure 2.1 Hevner presents a conceptual framework to position and compare the paradigm of behavioral science and design science. Hevner explains that IS research is composed organizational business needs which is positioned relative to existing technology infrastructure and development capabilities and in order to achieve research relevance for business needs, research activities need to be conducted. Hevner explains that two paradigm of IS research (Design Science and Behavioral Science) help in research through development of justification of theories that explain the phenomena related to the identified business need and creating/evaluating artifacts designed to meet those business needs. In short purpose of behavioral science is to seek truth and the purpose of design science is to provide utility.

The knowledge base provides foundational theories, frameworks, models, methods that may aid design researcher in reaching the research goals. The contributions of behavioral science and design science in IS research are assessed as they are applied to the business need in an appropriate environment and as they add to the content of the knowledge base for further research and practice.

This thesis focus on the design science research. The goal of this thesis is to identify the business needs and offer utility in form of an artifact. In the initial chapters we discuss the background and problem relevance, which mostly elaborates the business needs from end user point of view. The major step of this thesis is to design a noise measurement system and provide a software artifact which enable end user to carry out the measurement task. For the sake of research purpose and organizational needs system design is developed using DMM3458A, Agilent 33220A and C# programming language. In the later portion of the thesis, the design has been justified and evaluated using Hevner’s design evaluation methods. As proposed by Hevner there are five approaches for evaluation in design science.
<table>
<thead>
<tr>
<th>Evaluation type</th>
<th>Evaluation method</th>
<th>Appropriation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observational</td>
<td>Case study.</td>
<td>In detailed information about the problem is presented in the first few chapters.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No field study is appropriated since the aim is to design/develop noise measurement system and analysis of data acquisition capabilities with measurement instrument.</td>
</tr>
<tr>
<td></td>
<td>Field study.</td>
<td></td>
</tr>
<tr>
<td>Analytical</td>
<td>Static Analysis</td>
<td>See chapter 3.</td>
</tr>
<tr>
<td></td>
<td>Architectural analysis.</td>
<td>See chapter 3.</td>
</tr>
<tr>
<td></td>
<td>Optimization.</td>
<td>Did not perform yet.</td>
</tr>
<tr>
<td></td>
<td>Dynamic analysis.</td>
<td>Did not perform yet.</td>
</tr>
<tr>
<td>Experimental</td>
<td>Controlled experiment.</td>
<td>There are number of experiments for which the system has been tested and further developed.</td>
</tr>
<tr>
<td></td>
<td>Simulation.</td>
<td>There design is simulated on different stages in the development of noise measurement system.</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>Testing</td>
<td>Functional testing or black box testing.</td>
<td>The expected behavior of the system has been tested through the development and execution of example applications, which is comparable to black box testing.</td>
</tr>
</tbody>
</table>
Structural testing or white box testing.

The code has been put under continuous testing and re-factoring in number of design iterations.

<table>
<thead>
<tr>
<th>Descriptive</th>
<th>Informed arguments.</th>
<th>See chapter 4.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario</td>
<td></td>
<td>See chapter 5.</td>
</tr>
</tbody>
</table>

**Table 2.1** Five approaches for evaluation in design science (Hevner et al (2004))

This thesis aims to conduct several evaluation methods (See Table 2.1) as proposed by Hevner design research. In the static analysis the aim is to explain the general theory of noise measurement system design, and highlight the important concepts about different terms related to system design and development. The architectural analysis gives the insight of design principles and techniques to develop noise measurement system. Using the evaluation method, descriptive evaluation has been divided into two sections, namely Informed arguments and Scenario. In case of informed arguments, the background knowledge, relevant theories, system design and hardware in use has been discussed in detail. It shows the use of background knowledge and relevant material for the design and development of noise measurement system. In the scenario section, a complete example of setting up and using noise measurement system has been shown.
Hevner Design-Science Research also mentions some guidelines in order to conduct the research which have been utilized and shown in the following table:

<table>
<thead>
<tr>
<th>Guideline</th>
<th>Description</th>
<th>Appropriation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design as an Artifact</td>
<td>Design science must produce a viable artifact</td>
<td>This thesis research led to the design and development of noise Measurement system</td>
</tr>
<tr>
<td>Problem Relevance</td>
<td>Highlight the importance of the problem to the working world and show that it adds value</td>
<td>In the introduction and problem relevance section. The importance of noise measurement system is highlighted</td>
</tr>
<tr>
<td>Design Evaluation</td>
<td>The artifact should be evaluated using well defined evaluation methods</td>
<td>Evaluate the system using several evaluation method proposed by hevner.</td>
</tr>
<tr>
<td>Research Contribution</td>
<td>The artifact should provide a contribution to the design process</td>
<td>See Chapter 6.</td>
</tr>
<tr>
<td>Research Rigor</td>
<td></td>
<td>See Chapter 6.</td>
</tr>
<tr>
<td>Design as a Search process</td>
<td></td>
<td>See Chapter 6.</td>
</tr>
<tr>
<td>Communication of Research</td>
<td></td>
<td>See Chapter 6.</td>
</tr>
</tbody>
</table>

Table 2.2 Hevner Design-Science Research also mentions some guidelines

2.1) Outline:

We begin by describing the working of electron microscope and the importance of current/voltage stability in reducing noise. We continue by describing the major sources of noise that can occur and the type of noise we would mostly be dealing in the current case, the approaches taken to deal with these noise sources.

The structure of the thesis is as follows: Section-1 consists of several subsections which firstly introduces the topic of noise measurements and give background details. Problem, aim, research questions, and delimitations conclude the first chapter. Section-2 introduces research methodology, framework and design process that is followed to carry out the research. Section-3 Covers the literature review/knowledge base of the thesis. In this section principle of SEM operation is discussed with some other important concepts used in this thesis. It is recommended for the reader who is unaware of the working/principle of electron microscope and fundamentals of electronics. Section 4 covers the different sources of noise and it’s impact in detail. In Section 5 the design of noise measurement system is proposed. Section 6 covers the evaluation as proposed by hevner. Later section covers the conclusion, future work, references and appendix.
3) Literature Review:

In this section the focus is to gather working principles, theories, manual and research that are related to the problem domain. The problem at hand is complex for a person with IS background as most of the concepts that are used are taken from different fields of electronics and electron microscopy. Therefore I have tried to explain the main concepts that I will be discussing later on. For a reader who is acquainted to the concepts about secondary electron microscopy and electronics may not need to go through this section. However later part of this section also cover the source of noise and stability requirements, which I recommend reading for clear understanding of the problem.

3.1) Principles of SEM operation

Wikipedia defines electron microscope as: A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons.

A scanning electron microscope is a machine comprised of an electron generating component called the gun, a column through which the electron beam travels, a series of lenses to shape the electron beam, the sample chamber at the base, and a series of pumps to keep the system under vacuum. Below are some topics that help explore inside the machine and how the electron beam interacts with the sample.

- Layout
- The electron gun
- Electromagnetic lenses and beam size
- Acceleration voltage vs. specimen type

3.1.1) LAYOUT:

The basic layout of SEM consist of column that uses a beam of high energy electrons generated by an electron gun. These electrons are handled by magnetic lenses, focused at the specimen surface and systematically scanned (rastered) across the surface of a specimen. Unlike the light in a light microscope (LM), the electrons in a scanning electron microscope (SEM) never form a real image of the sample. The SEM image is an electronic image and is in the form of a serial data stream. It is a result of the beam probe illuminating the sample one point at a time in a rectangular scanning pattern (raster), with the strength of the signal generated from each point being a reflection of differences (e.g. topographical or compositional) in the sample.

![Figure 3.1.1 SEM Layout and Function](image-url)
The formation of an image requires a scanning system to construct the image using the serial data stream. The scanning system uses two pairs of electromagnetic deflection coils (scan coils) that scan the beam along a line then displace the line position to the next scan so that a rectangular raster is generated both on the specimen and on the viewing screen. The purpose of first pair of scan coil is to bend the beam off the optical axis of the microscope, while the second pair serves the purpose of bending the beam back onto the axis at the pivot point of the scan. It is very important to measure the signal intensity from the interaction of electron beam and specimen to produce contrast in images. Signals that are generated from the specimen are collected by an electron detector, passed through scintillator and photomultiplier and converted in to electric signals, which is used to modulate the image on the viewing screen.

3.1.2) THE ELECTRON GUN:
The electron gun refers to the top region of the SEM that generates a beam of electrons. The typical gun uses a heated tungsten wire to produce electrons. Modern SEM systems have requirement that the electron gun produces a stable electron beam with high current, small spot size, adjustable energy, and small energy dispersion. Several types of electron guns are used in a SEM system and the qualities of electrons beam they produced vary considerably. In modern SEM electron gun generally uses the field emission sources, which provide enhanced current and lower energy dispersion. Emitter lifetime is another important consideration for selection of electron sources.

The most widely used electron gun is composed of three parts: V-shaped hairpin tungsten filament (the cathode), Wehnelt cylinder and an anode, as shown in Figure. The tungsten filament is about 100 μm in diameter. In order to make sure electrons can escape from the filament surface, the filament tip is heated for a temperature of 2800 K by applying current. High power supply applied to the tungsten and Wehnelt cylinder is responsible for a negative potential, which varies in the range of 0.1-30kV.

As the anode is grounded, the electric field between the filament and the anode plate extracts and accelerates the electrons toward the anode. In thermionic emission, the electrons have widely spread trajectories from the filament tip. A slightly negative potential between the Wehnelt cylinder and the filament, referred to as “bias” provides steeply curved equipotential near the aperture of the Wehnelt cylinder, which produces basic focusing of electron beam. The focusing effect of Wehnelt cylinder on the electron beam is depicted in Figure.

![Figure 3.1.2. Electron Gun.](image-url)
Below the cap sits an anode, which, being positive, attracts the electrons away from the filament. If the filament is broken, the beam current will not increase on the SEM because no electrons can be produced.

![Beam produced by electron gun](image)

**Figure 3.1.2(b). Beam produced by electron gun**

The electron gun is used to provide a large, stable current in a small electron beam.

The electron gun produces a source of electrons and accelerates these electrons in an energy range typically 1-40kV. In case of a thermal emission, the tungsten filament is heated by a filament current. This results in the emitting of thermal electrons. The emitted electrons are those that have to overcome the work function energy of the material.

The hole in the anode allows a fraction of the electrons to continue down the column through the lenses to produce a smaller, more cohesive beam. Electrons that strike the anode are returned to the high voltage power supply via ground. The portion of the beam that leaves the anode through the hole is termed the beam current.

Two important key factors for any electron gun are the amount of current produced and the stability of current. In electron microscopy, the saturation point is the optimal point for the filament, at which maximum electron emission can be achieved; at the saturation point the beam is most stable.

The electron micrograph is a scanned image of discrete values taken from the specimen. A constant beam current is required to create a good quality image because all image information is recorded as a function of time. Since the micrograph is acquired over a period of time, usually at the slow scan rate to ensure photographs of high quality, any changes in the emission of electrons from the filament will affect the image intensity at that point in the scan. This will result in a low quality image because the brightness will differ across the image. A constant beam current is vital for saturating the filament properly.

### 3.1.3) ELECTROMAGNATIC LENSES AND BEAM SIZE

A series of electromagnetic lenses, usually two (condenser and objective) are used to reduce the diameter of the beam of electrons and to place a small, focused beam of electrons onto the specimen under study.

An electromagnetic lens is a tightly bound coil of wire through which current can flow. Because the current flow produces a magnetic field, the field pushes inwards into the hole towards the center. This behaves to shape the beam of electrons travelling in their natural spiral path down the central hole and onto the specimen.
The functionality of a lens is to change the path of the rays in a required direction. Glass or transparent plastic may bend light and are used in optical lenses. However, glass or plastic lens cannot be used in electron microscope as they will stop electrons. Electrons are charged particles and they can be bent in a magnetic field. These lenses are made with ferromagnetic materials and windings of copper wire. They are called electromagnetic lenses because they produce a focal length which can be changed by varying the current through the coil. The magnetic field defines electron paths in the same fashion that solid glass lenses bend light rays. In the influence of magnetic field, electrons assume a helical path, spiraling down the column. This helical path can easily be demonstrated at low magnification by changing the focus up and down to cause image rotation.

There are two lens sets namely, the condenser lens, which is at the top and the objective lens at the bottom. Each performs a specified job. The condenser lens convergences the electron beam to a spot below it, before the electron beam scatters out again, it is converged back again by the objective lens then down onto the sample. This initial convergence can be close to the lens, or further away. Its dependency is on the spot size control, Spot size is the size of the beam cross section at the surface of the sample. If the lens is closer to the lens, at the point of convergence the spot diameter is very small and if it’s further away from the lens then the spot diameter would be large at point of convergence. The diameter of this initial convergence affects the final diameter of the spot the beam makes on the sample.

The objective lens also has some influence over the diameter of the spot size of the electron beam on the specimen surface. But its main role is in focusing the beam onto the sample. a focused beam produces a smaller spot on the surface than an under or over-focused beam.
3.1.4) ACCELERATION VOLTAGE VS. SPECIMEN TYPE

In theory, an increase in accelerating voltage, the voltage applied to the electron microscope that accelerates the electron beam down the column will result in a higher signal and will consist of low noise in the final image. With a higher accelerating voltage the electron beam penetration is greater and the interaction volume is larger. Therefore, the spatial resolution of micrographs created from those signals will be reduced.

Accelerating voltage (kV or keV) is the voltage difference between the filament and the anode which accelerates the electron beam towards the anode. The accelerating voltage (kV or High Tension) of a typical SEM ranges from 0 to 30kV. In principle, the greater the kV, the greater the capability of penetration by the beam into the sample.
3.2) Saturating the filament

An important factor in using a electron gun is understanding saturation of the filament for stable electron beam emission. Saturation is achieved by letting more current pass through the filament, if this current is increased, the greater is the emission of electrons from the tip region. However a point is reached where the electron emission is at maximum and the current passing through the filament cannot be further increased. This point is called saturation. Letting more current through the filament after this point does not increase electron emission. It adversely shortens the life of the filament, or may even damage it. The relationship can be seen in a graph of filament current against electron emission (or brightness).

![Diagram showing filament saturation](image)

Figure 3.2. Filament Saturation
3.3) Digital Multimeter:

A multimeter or a multimeter, also known as a VOM (Volt-Ohm meter), is an electronic device that combines several measurement functionalities in one unit. A typical multimeter would include basic features such as the ability to measure voltage, current, and resistance. Digital multimeters (DMM) display the measured value in numerals.

A multimeter can be useful in fault finding and stability requirements, or a bench instrument/devices to a very high degree of preciseness. They are used to troubleshoot electrical problems in a wide array of industrial and laboratory devices such as electronic equipment, power supplies, and wiring systems. The Figure shows Agilent digital multimeter used in this project.

![Figure 3.3. Agilent DMM 3458A](image)

3.4) Function generator:

A function generator is usually a piece of electronic test equipment used to generate different types of electrical waveforms over a wide range of frequencies. Example of few types of waveforms produced by the function generator are the sine, square, triangular and sawtooth shapes. Function generators has it’s utility in the development, testing and repair of electronic equipment.

![Figure 3.4. Agilent 33220A Function Generator](image)

3.5) Digitizing:

Digitizing or digitization is the representation of an object, image, sound, document or a signal (usually an analog signal) by a discrete set of its points or samples(Wikipedia), it is the process of converting a continuous analog signal into a series of discrete samples. Digitizing is of two types, namely discretization and quantization.

Discritization is the process of reading of an analog signal at regular time intervals (frequency), sampling the value of the signal at a given point. Each of this reading is called a sample and may be considered to have infinite precision at this stage.
3.6) **Sampling and sampling rate:**

In digital signal processing, sampling is the changing of a continuous signal to a discrete signal. One example is the conversion of a sound wave (a continuous signal) to a sequence of samples (a discrete-time signal).

The sampling rate, sample rate, or sampling frequency \((f_s)\) defines the number of samples per unit of time taken from a continuous signal to make a discrete signal. The unit for sampling rate is hertz (inverse seconds, 1/s, s\(^{-1}\)), also known as sample per second. Figure 3.6 shows the continuous signal (green) with a sampled signal (blue) with a fixed sampling rate.

3.7) **Aliasing:**

In signal processing, aliasing refers to an effect that causes different signals to become indistinguishable (or aliases of one another) when sampled. It also refers to the distortion that results when the signal reconstructed from samples is different from the original continuous signal. In other words, the distortion due to an insufficiently high sample rate is known as aliasing. The process of sampling results in the periodic repetition of the original signal. If the \(f_s\) or the sample frequency is \(f_s>2f\), \(f\) being the measuring frequency, the original spectrum can be recovered which is not the case if \(f_s<2f\).
Aliasing distortion: In the figure the signal is sampled at half the sample rate due to which high frequency aliases itself as low and vice versa.

3.8) Sampling theorem:

The Nyquist or Sampling Theorem states:
“If a continuous, bandwidth-limited signal contains no frequency components higher than F, then the original signal can be recovered without distortion (aliasing) if it is sampled at a rate that is greater than 2F samples per second”.

In practice, the multimeter’s sampling rate must be at least twice the highest frequency component of the signal being measured (measuring frequency). If a signal has an upper band limit of 100 Hz, a sampling frequency greater than 200 Hz will avoid aliasing and would theoretically allow perfect reconstruction.

\[ f_s > 2f_m \]

\( f_s \) = Sampling frequency  
\( f_m \) = Measuring frequency

This theory is useful in selecting the sample frequency, once you know the measuring frequency, this has been put into practice in the design of the system so that we have appropriate selection of sample frequency in order to recover the original signal via digitization.
4) Noise Theories and Technique to Reduce Noise:

4.1) Different Types of noise:

Saeed v. vaseghi (2004) defines noise as unwanted signal that interfaces with the measurement of another signal. It is important for the noise measurement process to be aware of the different sources of noise and the components of instrument to be able to minimize the noise. The reduction of noise for measurement process ensures accuracy and factual limits of any instrument. Noise interference may occur due to environmental sources or result from the properties or limitations of the system. For the current thesis, we only consider the noise sources caused by the properties or usage of the system. Presence of noise limits the accuracy of results in noise measurement system, therefore it is very important step to model the removal of noise. The main type of noise associated with the electronic devices, that are of our interest:

1) Thermal Noise
2) Shot Noise
3) Flicker Noise

The major kinds of noise associated with electronic devices are thermal, shot, and flicker.

4.1.1) THERMAL NOISE:

Thermal noise is also referred as Johnson noise, is a type of electronic noise that is generated by random movements of thermally energised particles inside electric conductor, this happens irrespective of any applied voltage.

The root mean square (RMS) voltage due to thermal noise $v_n$, generated in a resistance $R$ (ohms) over bandwidth $\Delta f$ (hertz), is given by

$$v_n = \sqrt{4k_BT R \Delta f}$$

where $k_B$ is Boltzmann's constant (joules per kelvin) and $T$ is the resistor's absolute temperature (kelvin).

4.1.2) SHOT NOISE:

Shot noise in electronic devices consists of unavoidable random statistical fluctuations of the electric current. These random fluctuations are caused when the current flows and are small enough to give rise to detectable statistical fluctuations in a measurement.

The term shot noise come from the analysis of random variations in the emission of electron from the cathode of a vacuum tube. A stream of discrete packets in a current flow arrive at random times and therefore will cause fluctuations in the average particle flow. The fluctuation in the rate of arrival of Particle flow contribute to shot noise.

The presence of shot noise is evident from the fact that phenomena such as light and electric current consist of the movement of discrete (also called quantized) 'packets'. Light, a stream of discrete photons—coming out of a laser pointer and hitting a wall to create a visible spot. The core concepts behind light emission are such that these photons are emitted from the laser at random times; but these photons needed to create a spot are so many that the brightness and number of photons per unit time changes only immeasurably with time. However, if the laser brightness is reduced in such a way that only a some of photons hit the wall every second, the relative fluctuations in number of photons, i.e., brightness, will be significant, These fluctuations are shot noise (wikipedia)
4.1.3) FLICKER NOISE:

Flicker noise, also known as 1/f noise, is a signal or process with a frequency spectrum that falls off steadily into the higher frequencies. It takes place in almost every electronic device and results from a number of reasons, though always related to a direct current. It results from various reasons, such as crystal surface defects in semiconducter, impurities in conductive channel etc. Also, as flicker noise is related to direct current, it may be kept low if the level of direct current is kept low.

4.2) Signal to noise ratio:

Signal-to-noise ratio (often abbreviated SNR or S/N) is a measure that compares the level of a desired signal to the level of background noise. It is defined as the ratio of original signal strength to the noise strength. SNR is commonly quoted for electrical signals.

Signal-to-noise ratio is often as defined as the ratio of power between a signal (meaningful information) and the background noise (unwanted signal):

\[ \text{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}} \]

An alternative definition of SNR is as the reciprocal of the coefficient of variation, i.e., the ratio of mean to standard deviation of a signal or measurement.

\[ \text{SNR} = \frac{\mu}{\sigma} \]

where \( \mu \) is the signal mean or expected value and \( \sigma \) is the standard deviation of the noise.

4.3) Image Distrubances and their Causes:

Joelguide explains that the Image disturbances usually diverse in types, can be classified by the following expressions:
1) Images that are lacking sharpness and contrast
2) Images those are unstable
3) Images with poor quality in general
4) Images with noise
5) Images showing rough edges
6) Images that have unusual contrast
7) Images those are distorted or deformed.

The above-listed image disturbances, apart from defects in the instrument itself, are occasionally caused by the operator’s lack of experience, improper specimen preparation and external influences. Table 1 shows various image disturbances and their causes.

Joel suggest that above listed disturbance can be attributed to cases such as the following:
1) The mutual interaction between the specimen and the electron beam involves a problem.
2) Selection of observation conditions and specimen preparation involve a problem.
3) The instrument itself involves a problem.
4.4) **Probe Current, Probe Diameter and Image Quality:**

Probe current or spot size is defined as the size of the beam cross section at the surface of the sample. This affects

1) Resolution of the image
2) Number of electrons generated from the sample

A smaller objective lens aperture produces a smaller spot size. Also, a higher current through the condenser lens creates a smaller spot on the sample. It is therefore very important that the current source of electron beam (electron gun) and the lenses are very stable and the presence of noise which affects the image quality should not be tolerated. It is important to note that the type of noise we discussed earlier exist at some point in the system and cannot be fully eliminated. We want to establish a system which ensures optimum performance using the stability limits.

In the SEM, the magnification and resolution is higher if there is small electron probe diameter on the specimen, however, the S/N ratio depends on the probe current which effects the image smoothness. The probe current and the probe diameter are in relation to each other, reducing the probe diameter would decrease the probe current, this means that probe current and probe diameter are directly proportional to each other. It is therefore necessary to select a probe current suited for the magnification and observation conditions.
4.5) Stability Factors:

There are different stability factors that can effect the image quality of an electron microscope, it may be because of acoustic distrubance or the electronic device noise. We are mainly interested in the later. Earlier, while explaining about the electron gun we established the importance of stability of electron gun and the condenser lenses current, voltage. Similarly the need for ultra-stable power supplies for controlling the currents in magnetic lenses becomes one of the limiting factors. In electron optics magnetic lenses are used to refract and bend light rays for image formation. Magnetic force is used to change the direction of electrons in the same way that a lens changes the direction of light rays. Therefore one of the limiting factors of resolution in electron microscopy is variation of the current that creates the magnetic field. For systems, like magnetic lenses, the stability of the focusing properties is dependent on the stability of the current. Any minor changes in the current changes the focal length in the magnetic lens resulting in a decrease in resolution. With the advancement in lowering aberrations in electron microscopic lenses the need for higher stability in the lens current supplies becomes paramount.

For a magnetic lens, the focal length is related to current through the relation:

\[
f = \frac{K \cdot V_r}{(NT)^2}
\]
Where \( f \) = focal length,
\( K \) = a constant,
\( V_r \) = relativistic accelerating voltage,
\( I \) = current
\( N \) = number of turns in the excitation coil.

The above equation shows that the focal length varies inversely with \( I^2 \). Therefore, a fixed and stable focal length requires a stable current flowing through the magnetic lens. In order to see the importance of a stable current differentiate the equation:

\[
\frac{df}{dI} = \frac{d}{dI} \left( \frac{KV_r}{(NI)^2} \right) = \frac{-2KV_r}{N^2I^2} = \frac{-2f}{I^2}
\]

Rearranging the above equation we get:

\[
\frac{\Delta f}{f} = \frac{-2\Delta I}{I}
\]

The equation above shows that stability of the focal length is directly proportional to the stability of the current which is responsible for setting up the magnetic field in the lens/coils. Thus, it is very important to have a highly stable current source for magnetic lens.

4.6) Technique to reduce noise; Signal Averaging:

There are many procedures to reduce noise however the statistical technique of signal averaging is often used for reducing noise for data acquisition systems. In signal processing, signal averaging is applied in the time domain. The purpose of this technique is to increase the strength of the signal relative to the noise. This is done by averaging set of replicate measurements yielding increase in S/N ratio.

Signal averaging increases the signal-to-noise ratio. Suppose the noisy signal \( v(k) \) is sampled every \( T \) s

\[ v(kT) = v_s(kT) + v_{\text{noise}}(kT). \]

\( v_s(k) \) being the desired periodic signal and \( v_{\text{noise}}(k) \) the unwanted noise.

If \( N \) partitions are composed, the averaged signal becomes

\[ y(kT) = \sum_{i=1}^{N} v_s^i(kT) + \sum_{i=1}^{N} v_{\text{noise}}^i(kT), \quad \forall \; k = 1, 2, \ldots, M. \]

If the partitions are perfectly aligned and the signal is truly periodic, the desired signal adds up:

\[ \sum_{i=1}^{N} v_s^i(kT) = Nv_s(kT). \]

However, for Gaussian noise with zero mean and a standard deviation \( \sigma_n \) (which also equals
its rms value, we obtain

\[ \sum_{i=1}^{N} v_{\text{noise}}^i (kT) = \sqrt{N \sigma_n^2} = \sqrt{N} \sigma_n. \]

Taking the ratio of above equation, we can find the signal-to-noise ratio (SNR) after averaging \( N \) partitions:

\[ \text{SNR}_N = \frac{N v_s (kT)}{\sqrt{N} \sigma_n} = \sqrt{N} \times \text{SNR}_1 \]

Thus, we get an \( \sqrt{N} \) improvement in the SNR.
5) Design of the Noise Measurement System:

The main idea of this thesis is to build a synchronous noise measurement system, using a single multimeter, the measurement process is affected by the presence of noise that hinders the measurement process. Although digital multimeter DMM 3458a is used world over as the standard in high performance and high accuracy, using one multimeter for high stability requirements does not give us the right picture, as there is noise present in the input of the multimeter, not to mention the noise interference in the electron gun, power supply and the condenser lenses needs to measured accurately and there is very slight margin for error. If the stability requirements are effected, the noise disturbance can effect the whole imaging process of the microscope. It is to be noted, there is actually some benefit to having system noise in the first place. Noise added to a signal going into an analog-to-digital converter (ADC) can actually increase the resolution of the converter beyond the number of bits of resolution it provides.

Using the signal averaging technique, the idea was to devise a setup using multiple multimeter which can enable us to do synchronous measurements, based on the same time stamp. This would result in a high S/n ratio as compared to using single multimeter which would result in low S/n ratio (later shown in the evaluation section). A data acquisition part (software) which enables us to manipulate the setup for the instrument and get the readings. Once the data has been collected we transfer the data in matlab to analyze with signal averaging algorithm design.

![Figure 5.1. Setup for noise measurement System.](image)

For the current system design we used four digital multimeter and a function generator, bnc cables and four GPIB bus. The purpose of four GPIB is due to the protocol and data limitation of GPIB. After understanding working of the instrument, data acquisition was initially done to check the data rates and accuracy of data using one instrument. It was established as a requirement from the user that 1000/s per instrument is the maximum date rate we want to achieve. The reason for putting a limit on the data rate was because usually noise measurements are done slow in order to avoid noise as the instrumet has longer integration time and you do not produce higher data rate. For somecases you might need to go higher data rate but that can produce more noise in the system and effect the synchronization process therefore it is generally avoided.

One important step of the measurement process was the continuous readings generations. So that once the instrument (multimeter) is triggered it starts the reading continuously and the readings go on basis of the sample rate adjusted. The reason behind the using continuous reading generation is the fact that we want to achieve signal averging over time measurements. If we lose some data points it will effect the averging process which would directly effect the noise measurement results. So it is very important that once the multimeter is triggered, multimeter produce digitized points continuously. We achieved this by using a function generator. Function generator triggers the multimeter to produce continouse measurements. We used external source to trigger the multimeter beacuse of limiting specifications of the multimeter.

Bnc cables were used to connect function generator and the multimeters together, there was one multimeter which was directly connected to the function generator and the rest of the multimeter were connected with each other. Function
generator was connected to the back pannel (Trig Ext) , while bnc cable was connected from Trig Extout to Trig Ext of the other multimeter and this pattern was repeated. The purpose of this arrangement was to have a single trigger source ,which triggers the four instrument on the same timestamp so that the readings are in synchron and continous. After making sure the readings are synchronized the next step included a data acquisition unit, a software system which enable readings from the instrument via GPIB bus in a synchron manner. For this purpose a multithreaded application was built to read in the data points on the same time stamp, this was also an important system for the data acquisition to be accurate , it was of very vital importance that readings are read by the software system were on the same time stamp (synchron). The read/write process does not affect/slow down the measurement process. Writing results to csv was done at the same time reading was done so that for readings that take longer period of time user may be able to check results in between.

For the validity of results, data from csv file is imported to matlab and using averaging technqiue, RMS noise is calculated. In the later secion of evaluation it has been shown by multiple tests that show that RMS noise is reduced by using four instrument as compared to using single instrument.

![Diagram](image.png)

Figure 5.2. Shows the flow of the system.
6) Evaluation of Noise Measurement System:

The noise measurement system remains to be tested in practical laboratory setting. There is no test on the efficacy of the imaging or original microscope using this system. However, we are able to demonstrate different attributes of this system. In the first section black box testing and white box testing is done. This is classified as approach that corresponds to Hevner et al’s (2004) evaluation method. In the second section of this chapter we discuss the utility of the system by showing synchronous measurements and noise reduction of data by averaging, these two steps were very important for evaluation as the whole accuracy of system depended on these two criteria. We classify these as experimental and scenario based evaluation as presented by Hevner et al (2004).

6.1) Testing:

Testing is very important to check the efficacy and utility of the system, depending on the nature of testing, it can lead to various useful facts about bugs and related issues with the system. It is therefore very important check for different measures that can impact the consistancy and accuracy of the system. Through out the development phase, the system was put under various tests, there was lot of non-symmetric testing done with the development of system. Test cases were developed keeping in mind the important pathways of the system, functionality and usability. The test cases that were established with the mutual interest of end user at the end of system of development were:

6.1.1) TEST-CASE: ALL SETUPS ARE DONE CORRECTLY FOR THE INSTRUMENT:

To understand that all setup was done correctly for the instrument we need to understand how the program flow takes place and how the setup are manipulated with different setting on the interface.
The above figure show the different pathways user can choose from interface for each of the above scenario. For this, the DMM 3458a was adjusted and checked for the setup. This was checked using Agilent IO suite which give a utility to see the commands on a particular timestamps as they are sent to the instrument. Moreover, there was also manual checking of the setups by manipulating options from the front panel of the multimeter. After 10 tests it was concluded that all setups were done correctly from the program.

6.1.2) TEST-CASE: CHECK IF EXACT NUMBERS OF DATA POINTS ARE GENERATED FOR CERTAIN DURATION OF TIME IN A CONTINUOUS MANNER AND POINTS ARE NOT SKIPPED:

The test was taken to understand if there is any point skipping while taking measurements. The importance of this test can be understood from the fact that averaging on data with skipping values would produce undesired results. Thus before reaching synchronization with the acquired data points, it was checked with 20-30 tests across different sample rate and duration that we get the right number of points each time.

Number of points generated was calculated by: No of points = Duration/Sample Rate in Seconds, for example if we sample at the rate of 100 ms for a duration of 100 seconds, number of points generated will be 1000. This is the exact number of points generated after test. Few test results are shown below:

<table>
<thead>
<tr>
<th>Duration(s)</th>
<th>Sample Rate (s)</th>
<th>No of points generated</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.1</td>
<td>1000</td>
</tr>
<tr>
<td>10</td>
<td>0.1</td>
<td>100</td>
</tr>
<tr>
<td>1</td>
<td>0.001</td>
<td>1000</td>
</tr>
<tr>
<td>60</td>
<td>0.001</td>
<td>60000</td>
</tr>
</tbody>
</table>
Figure shows 100 points generated as a result of running duration of 10 seconds and sample rate of 100 milliseconds.
6.2) Evaluation based on Scenario:

Scenarios are very important to understand the utility of the artifact. Requirement for evaluation was based on consent of the end-users. It was established through discussion about the working of software that two evaluation need to be carried out in order to understand the accuracy of the system

1) Scenario based evaluation for synchronous measurements
2) Scenario based evaluation for noise measurements

6.2.1) SCENARIO BASED EVALUATION FOR SYNCHRONOUS MEASUREMENTS:

Scenario based evaluation is based on the idea that synchronous measurements are necessary to analyze averaging of the measurements. It is therefore important that the measurements are continuously timed. For the evaluation purpose 20-30 tests experiments were carried out with different sample time and duration to check for synchronous measurements. User started the system by choosing the digitizing method (DCV) Or (DCI) and select the necessary parameters, which includes specification of Aper and Sampletime. Once the setup was done on the interface, Measurements were started, this triggered the function generator which selected the sampling frequency. After setting the parameter for function generator all multimeters were triggered at the same time. This was made sure using TPL(task processing library) to run four parallel task. This evaluation was done on the basis of data gathered from these experiments, experiments were done sample rate of 1kh,2khz,3khz,4khz with 10 iterations for each test. It was seen by the plot function of matlab that synchronization was not lost at 1khz sample rate but at higher sample rate points were lost which as result effected the synchronization process.

Example of Synchronization test:

Duration of Experiment: 70 hours
Setup:
DMM1 :Function: DC Voltage,Range:10V,LineSyncoization:No,SampleTime:0.1s,AZERO OFF,FixedZ_10GΩ,Aper:200µs
DMM2: Function: DC Voltage,Range:10V,LineSyncoization:No,SampleTime:0.1s,AZERO OFF,FixedZ_10MΩ,Aper:200µs
DMM3: Function: DC Voltage,Range:10V,LineSyncoization:No,SampleTime:0.1s,AZERO OFF,FixedZ_10MΩ,Aper:200µs
DMM4: Function: DC Voltage,Range:10V,LineSyncoization:No,SampleTime:0.1s,AZERO OFF,FixedZ_10MΩ,Aper:200µs
a) Synchronization Test, Plot at ending points

b) Synchronization Test, Plot at mid points
The Above three plots show the synchronization test. Figure (a,b,c) shows that the data for four instrument is synchronized. It was seen by the plot function of matlab that synchronization was not lost at 1khz sample rate.

6.2.2) SCENARIO BASED EVALUATION FOR NOISE MEASUREMENTS:

The evaluation for noise measurement is done to prove that noise is actually reduced by using multiple digital multimeter (four in our case), by the theory of signal averaging. The technique used for this evaluation is also based on 20-30 tests experiments that were carried out to gather synchronous data and analyzing it in matlab, it was later processed through the averaging algorithm to see the changes in RMS values, by series of experiments and data collected it was shown that RMS was reduced by a factor of 10 using multiple instruments.

Overnight test 16 hours:
Subset reading (9500) plot
SampleTime:1s,AZERO ON ,Aper:0.20
RMS DMM1 is equal to 4.863313e-007
RMS DMM2 is equal to 4.975407e-007
RMS DMM3 is equal to 5.298891e-007
RMS DMM4 is equal to 5.640488e-007
RMS is equal to 3.267470e-007

The above plot shows square wave of multiple colors. Purple, teal, red and green show the data plot of four different multimeter. It is important to note here that these plot are well synchronized for us to apply the averaging algorithm. The blue plot on the top is actually the output of averaging algorithm which shows a reduction in noise. This noise reduction in terms of RMS (root mean square) is given for each multimeter. Using the averaging technique, RMS noise was reduced by a factor of 10. This is a significant reduction for precise noise measurements.

Duration 100 Seconds:
Setups:
DMM1: Function: DC Voltage, Range: 10V, Line Syncroization: No, Sample Time: 200ms, AZERO ON, Fixed Z_10GΩ, Aper: 0.2ms
DMM2: Function: DC Voltage, Range: 10V, Line Syncroization: No, Sample Time: 200ms, AZERO ON, Fixed Z_10MΩ, Aper: 0.2ms
DMM3: Function: DC Voltage, Range: 10V, Line Syncroization: No, Sample Time: 200ms, AZERO ON, Fixed Z_10MΩ, Aper: 0.2ms
DMM4: Function: DC Voltage, Range: 10V, Line Syncroization: No, Sample Time: 200ms, AZERO ON, Fixed Z_10MΩ, Aper: 0.2ms

B) Reducing noise test(100 Seconds)

RMS DMM1 is equal to 2.429942e-005
RMS DMM2 is equal to 2.401685e-005
RMS DMM3 is equal to 2.446865e-005
RMS DMM4 is equal to 2.418751e-005
RMS is equal to 1.328456e-005

The above plot shows a 100 second experiment, listed below the duration are setups done on DMM 3458A. These setups are necessary in order to set the sample rate and other options which are required to bring multiple DMM in synchronization. Above Figure shows square wave of multiple colors. Purple, teal, red and green show the data plot of four different multimeter. The blue plot on the top is actually the output of averaging algorithm which shows a reduction in noise. The result of this experiment also conclude the importance of signal averaging as we are able to see RMS reduction by a factor of 10.
I have put three tests of RMS noise reduction by signal averaging below. For the last two tests I have selected a much longer duration for the experiment exceeding 1 and 2 hours. The purpose of long duration experiment is to analyze the effect of noise over period of time. It is very important that minimum noise takes part even in case of long measurements as most of the noise tests are slow measurement test. It is clear for the gathered RMS data that even after duration of 1 or two hours average RMS is less than the individual RMS of each instrument.

Duration 100 Seconds:
Setups:

DMM1: Function: DC Voltage, Range: 10V, LineSyncroization: No, SampleTime: 200ms, AZERO ON, FixedZ_10GΩ, Aper: 20ms
DMM2: Function: DC Voltage, Range: 10V, LineSyncroization: No, SampleTime: 200ms, AZERO ON, FixedZ_10MΩ, Aper: 20ms
DMM3: Function: DC Voltage, Range: 10V, LineSyncroization: No, SampleTime: 200ms, AZERO ON, FixedZ_10MΩ, Aper: 20ms
DMM4: Function: DC Voltage, Range: 10V, LineSyncroization: No, SampleTime: 200ms, AZERO ON, FixedZ_10MΩ, Aper: 20ms

C) Reducing noise test(100 Seconds)

RMS DMM1 is equal to 6.652605e-007
RMS DMM2 is equal to 7.657218e-007
RMS DMM3 is equal to 7.041173e-007
RMS DMM4 is equal to 6.803619e-007
RMS is equal to 3.978293e-007

Duration: 1 hour 30 minutes (approx.)
Setups:

DMM1: Function: DC Voltage, Range: 10V, LineSyncroization: No, SampleTime: 1s, AZERO ON, FixedZ_10GΩ, Aper: 0.20
DMM2: Function: DC Voltage, Range: 10V, LineSyncroization: No, SampleTime: 1s, AZERO ON, FixedZ_10MΩ, Aper: 0.20
DMM3: Function: DC Voltage, Range: 10V, LineSyncroization: No, SampleTime: 1s, AZERO ON, FixedZ_10MΩ, Aper: 0.20
DMM4: Function: DC Voltage, Range: 10V, LineSyncroization: No, SampleTime: 1s, AZERO ON, FixedZ_10MΩ, Aper: 0.20
D) Reducing noise test (1 hour 30 minutes)

RMS DMM1 is equal to 5.795677e-007
RMS DMM2 is equal to 5.052319e-007
RMS DMM3 is equal to 4.933147e-007
RMS DMM4 is equal to 5.773380e-007
RMS is equal to 3.642425e-007
Duration: 2 hour 30 minutes (approx.)

DMM1: Function: DC Voltage, Range: 10V, LineSyncroization: No, SampleTime: 1s, AZERO ON, FixedZ_10GΩ, Aper: 0.20

DMM2: Function: DC Voltage, Range: 10V, LineSyncroization: No, SampleTime: 1s, AZERO ON, FixedZ_10MΩ, Aper: 0.20

DMM3: Function: DC Voltage, Range: 10V, LineSyncroization: No, SampleTime: 1s, AZERO ON, FixedZ_10MΩ, Aper: 0.20

DMM4: Function: DC Voltage, Range: 10V, LineSyncroization: No, SampleTime: 1s, AZERO ON, FixedZ_10MΩ, Aper: 0.20

E) Reducing noise test (2 hour 30 minutes)

RMS DMM1 is equal to 4.863313e-007
RMS DMM2 is equal to 4.975407e-007
RMS DMM3 is equal to 5.298891e-007
RMS DMM4 is equal to 5.640488e-007
RMS is equal to 3.267470e-007
7) Concluding discussion:

Hevner et al. (2004) presents a conceptual framework to position and compare the paradigm of behavioral science and design science. Hevner explains that IS research is composed organizational business needs which is positioned relative to existing technology infrastructure and development capabilities and in order to achieve research relevance for business needs, research activities need to be conducted. Hevner explains that two paradigm of IS research (Design Science and Behavioral Science) help in research through development of justification of theories that explain the phenomena related to the identified business need and creating/evaluating artifacts designed to meet those business needs. In short purpose of behavioral science is to seek truth and the purpose of design science is to provide utility by creating new and innovative artifacts.

Using the underlying theory of information system and conceptual framework proposed by Hevner The current thesis focus on the research in noise measurement and provided justification of the theories and explained the real world problem in term of user needs. I started by identifying the user needs and designing a noise measurement system based on these theories/ background knowledge. I created/ evaluated the system using certain techniques mentioned by Hevner DSR framework. The result was an artefact in the form of a noise measurement system that provided implementation and design of noise measurement system.

Using DSR framework (Hevner,2004), the goal is to seek an extension to the boundaries of human and organizational capabilities by finding solutions to new problems and creating new and innovative artifacts. In this thesis we do so by presenting a design and implementation of a noise measurement system. We have gathered information for knowledge base from previous facts, research, theories and meetings with stake-holder. We presented the design of the noise measurement system as well as justify it by testing and scenario based evaluation as proposed by Hevner(2004). Using the DSR methodology by Hevner we provide the degree of innovation in our work by highlighting high stability requirement for electron microscope power supply, lenses and electron gun and proposing a design artifact to achieve high precision synchronous measurements. We have shown this by evaluation of continuous timed measurements which are synchronized and results presented of few test which show reduction of RMS value by a factor of 10. This reduction in RMS values support the idea behind synchronous data acquisition using four multimeter instead of one.

Regarding the research implications for noise measurement system, we came with the conclusion that there are a number of research papers that highlight the importance of noise measurement with respect to electron microscope design. We find it hard to find design contribution of artifacts that present noise measurement system using multiple multimeters. There are number of noise reduction techniques in theory but for current scope we only focused on the averaging technique to reduce noise. Our work can be described as design proposition for noise measurements to problem described by Joel guide and Maryam.

7.1) Future Work

This research work has opened possibilities for future work. We believe that there is possibility of work for the improvement and exploration of design artifacts for noise measurement system. We came to the conclusion of thesis report by discussing some future possibilities of improvement:

1) Explore Increased Reading Rate:
The current system has a limit of 1000 readings per second that can be read via GPIB for measurement purpose. One work could be to explore the possibility of using higher data rate, going across this limit so that it does not hinder the synchronous results.

2) System for noise measurements:
Although this thesis only used DMM 3458a, but software was built, keeping in mind that more instruments can be added in future

3) GUI improvement:
Inclusion of real-time plot for the data gathered from four instruments

4) Check data with other noise filters
One important step for future work would be to check the data collected with different noise filters using Matlab.
8) References:
Author(s), Book Title. Place of publication: Publisher, year, page number(s).


[18] High Stability Current Supply For Electron Microscopy, Motamedi, Maryam Melani, pp. 20-26

[19] http://escholarship.org/uc/item/7f64w74q

9) Appendix

DMM : Digital multimeter
SEM : Scanning electron microscope
RMS : Root Mean Square
SNR : Signal to noise ratio