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SYS625 Requirements Document for TD Digitizers

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Lawrence Livermore National Laboratory

Requirements Document for Target Diagnostic Digitizers

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15

Contents

Standard Auspices Statement

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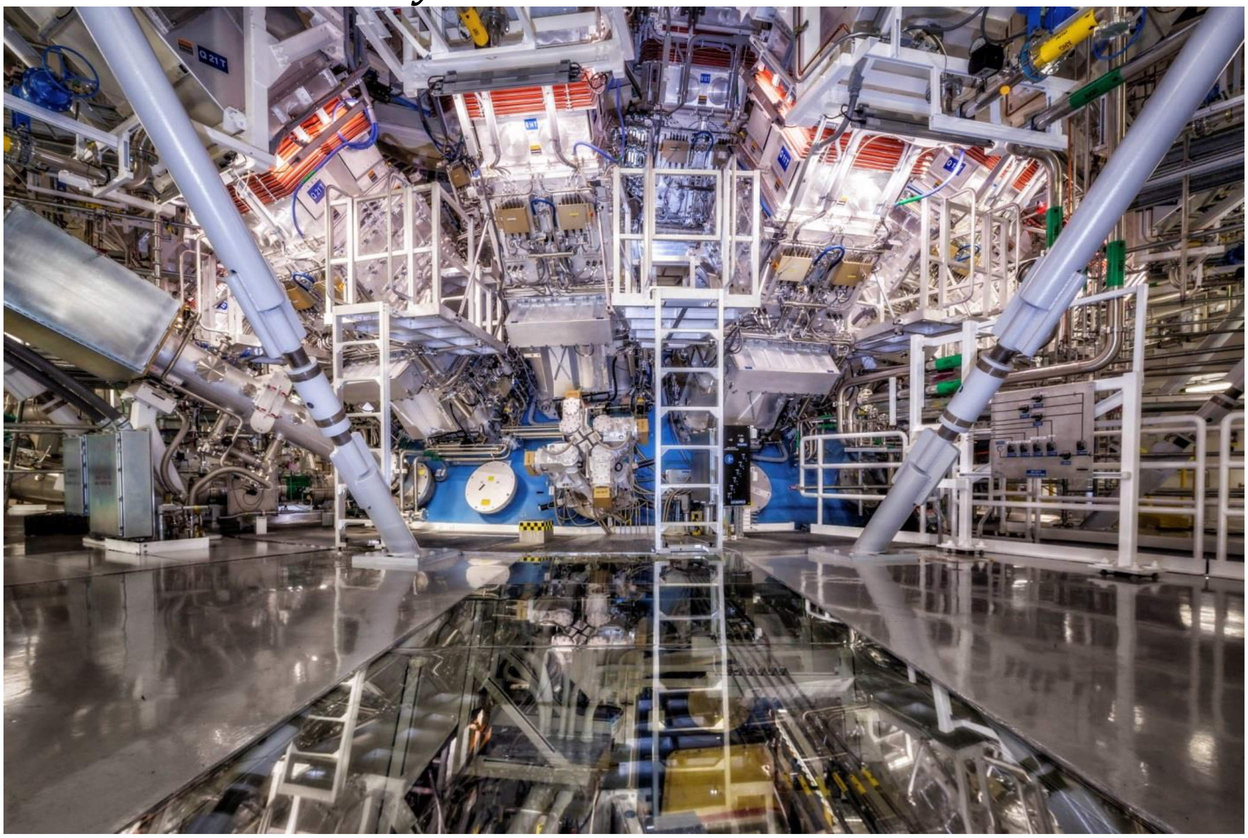
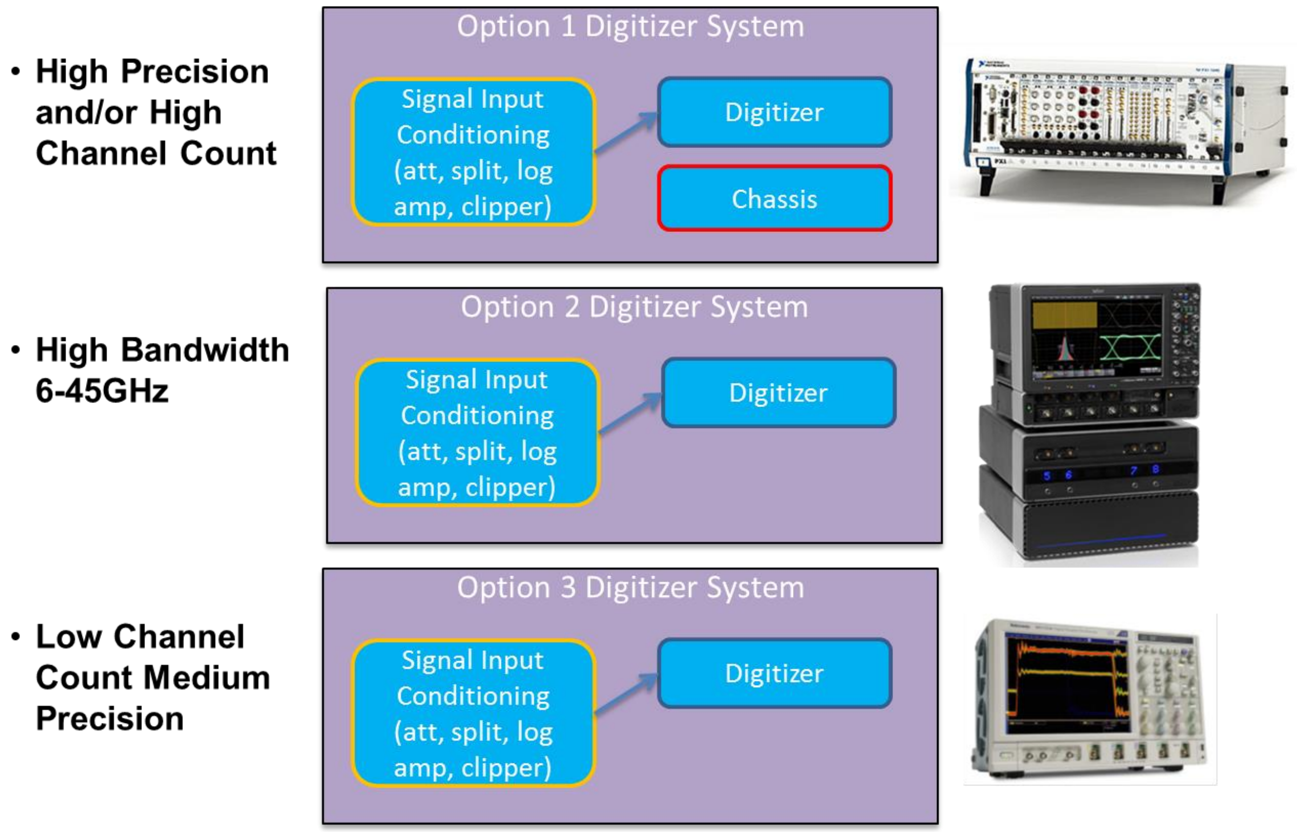
1 Executive Summary



The National Ignition Facility is the largest high energy density science facility in the world. Currently of the 60+ Target Diagnostics, at least fifteen use a type of high speed electrical signal data read-out device leading to over 200 digitization channels spread over six types of CRT (Cathode Ray Tube) and digital oscilloscopes, each with multiple models and versions. Every diagnostic is designed to measure a specific physical phenomenon resulting in different requirements for each digitizer. Though there has been some effort to use standardized readout architecture this formal system engineering analysis yields benefits for new systems and upgrades to existing diagnostics. Some of these benefits include reduced initial build cost, operational efficiency, reducing consumed rack space, reducing rack heat loading, planning for common spares, improving reliability, improving data quality, and reducing long term operational costs.

The NIF became an operational science facility in 2009 and was designed to have at least a 30 year operational lifetime. If a typical life cycle for a digitizer is 3 years of sales and an additional 5 years of manufacturer support, then in order to keep NIF diagnostics using state of the art, manufacturer supported, digitizers they will all need to be replaced three times over the life of the project. If a typical digitizer channel cost is between $10k and $40k the long term cost to the facility will be a substantial. The benefits from a common digitizer architecture developed from a system engineering analysis can have a lasting impact on the success of NIF.

The conclusion of this systems engineering analysis is that there should be a total of three architectures for all future diagnostics based on two parameters, bandwidth and channel count. Additionally, the use of channel input circuits (protection and/or signal modification) is needed and will be implemented to maintain the current reliability standard and allow for the transition away from CRT based oscilloscopes.   The top level architectures shown below cover all foreseeable digitizer needs for Target diagnostics in the NIF.



This systems engineering analysis was performed on existing Target Diagnostic Systems to inform future diagnostics and upgrades. The mission of Target Diagnostic is to assess the performance of target shots at the NIF. Every diagnostic has at a minimum a Responsible Scientists (RS) tasked with setting up and analyzing data coming from the system and Responsible System Engineer (RSE) tasked with managing all other aspects of the diagnostic. Additional key stakeholders such as management and facility restrictions informed this analysis.

The key acceptance criteria defining success or failure are maintaining performance equal to or greater than that of existing systems (no compromise on data quality or performance), reduce rack space (facility physically limited), and use commercial availability and vendor supported components. The purpose of this analysis is to lay out a simple plan for future diagnostics to use however doing this by analyzing existing systems is inherently limited to the current understand and needs of the stakeholders. These needs and expectations are undoubtedly going to change in the next 30 years, so before any new system has its requirements drafted a brief systems engineering analysis should be performed to verify that the conclusions and requirements laid out in this document are still valid.

2 Mission Description

2.1 Mission Statement

Develop a flexible digitizer implementation that will save rack space provide a standard architecture for future diagnostics.

2.2 Mission Scope, Objectives, Goals, and Needs

The scope of this analysis was limited to the existing digitizer based target diagnostic system in the NIF. It should be mentioned that there are other groups within the NIF including laser diagnostics and the Master Oscillator Room (MOR) that use digitizer. These additional groups may benefit from the analysis and high level architectural approach explained in this document however their specific needs and expectations were not included in this analysis.

The approach taken was to analyze existing systems to inform future designs. System that were included in the analysis are the nTOFs, DANTE, SPBT, GRH, FFLEX, FABS, NBI, EMP, SGEMP and DIM based framing camera pulse monitors. The specifics of each diagnostics are discussed in more detail in section 3.1. Performing analysis on fully operational "mature" systems allows for a more complete understanding of the initial needs and how they changed as the system evolved. This document is not intended to address the specific needs of any single system instead it layouts a guide for future diagnostics to leverage during their conceptual design and requirements phases.

Currently digitizers used in NIF are large, expensive, do not scale well and some require frequent repairs and calibration. Target Diagnostics needs a plan for addressing the needs of new diagnostics while maintaining the functionality of existing systems over the 30 year lifetime of the NIF. This systems engineering analysis lays out the current needs, solutions, and a preliminary set of tests to determine the best implementation of this solution.

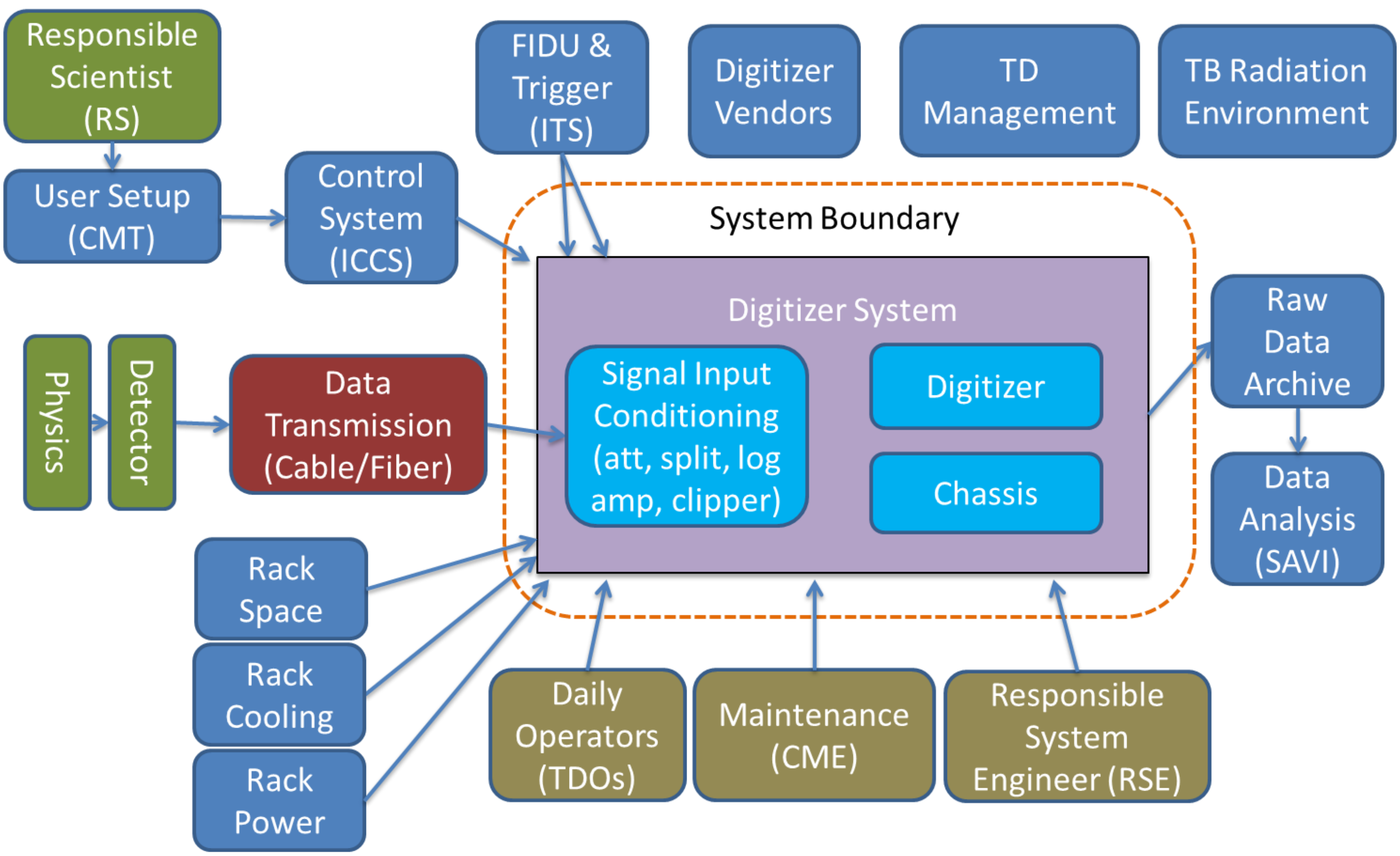
2.3 Lab Cultural Context

When performing a system engineering analysis at an institution such as Lawrence Livermore Nation lab with over 50 years of technical excellence it is important to be aware of the trappings that this culture can bring. Generally speaking, missions are driven by individuals with a scientific background not an engineering background (example: the typical education of lab directors). For NIF target diagnostics the priority of the scientist is to understand the physical phenomena that the diagnostic is designed to measure not develop a detector system. Moreover newer scientists typically come from an academic background where they worked in relatively small labs with smaller scale instrumentation setups. This can lead to a perspective that instruments on NIF can simply be larger versions of the ones they are familiar with. More senior scientist have experience with similar systems implemented in the past or at other facilities which generally leads to an initial approach that new system should be implemented in the same way, with never version of the equipment used previously, to minimize risk. These are gross generalizations that certainly do not apply to all LLNL scientists however it is important to be aware of what the baseline culture is surrounding the topic to perform a quality system engineering analysis. This means that new approaches are sometimes seen as risky and require more through testing and verification before they will be accepted.

2.4 Context Diagram

Digitizers constitute a small part of a typical target diagnostic system. A context diagram for digitizers shown below with active stakeholders and passive stakeholders. One objective of the "To-Be" architecture is to removed or minimize daily routine interaction with the system by people. The context diagram below shows TDOs (Target Diagnostic Operators), maintenance, and the RSE (Responsible System Engineer) interacting with the system however this is not a daily interaction.

The purpose of a diagnostic is to measure data. The context diagram shows the data path, starting with the physics that needs to be measured, then it is detected and turned into an electrical signal in the detector, passed down a data transmission system, where it then it enters the system boundary. The system consists of 3 components however some implementations depending on specific diagnostic requirements may only have one or two of these elements. Every system will have a digitizers, if many channels are needed this digitizer will be a card placed in a chassis. If there is a need to protect the digitizer due to the potential for damaging signals an input conditioning circuit will be installed. After the data is analyzed it is passed to the data archive where it can be analyzed by automated software analysis or by the RS. The RS then can use this data to determine what settings may need to be changed for the next experiment and setup the diagnostic using software tools and the process starts all over again when the next NIF shot fires.



2.5 Stakeholders

Stakeholders for

Rank	Role	Active or Passive
1	TD Management	Passive
2	Responsible Scientist (RS)	Passive
3	Responsible System Engineer (RSE)	Active
4	Maintenance	Active
5	Racks (Space, heat load, and power)	Active
6	Digitizer Vendors	Passive
7	Nature	Passive
8	Detector & Transducer	Passive
9	Data Transmission System	Active
10	FIDU and Trigger System (ITS)	Active
11	Control Systems (ICCS/TD IBCs)	Active
12	Target Diagnostic Operators (TDOs)	Active
13	Data Analysis Systems (Archive Viewer)	Passive
14	Shot Setup (CMT)	Passive
15	TB Radiation Environment	Passive
16	Data Archive	Active

2.5.1 Active Stakeholders

Active Stakeholders are individuals, organizations, things, other systems and networks and databases which will actively interact with the system once it is operational. For the purposes of this analysis there are individual people, other NIF systems (both control and data bases), the physical location (racks etc), the c

- **Responsible System Engineer:** This individual is responsible for making sure the diagnostic meets all of its functional requirements. They work with all the stakeholders (passive and active) to design new diagnostics, implement upgrades, perform non-routine maintenance, write maintenance and operating procedure, train operators, communicate status to management, hold weekly meeting as necessary, and generally are the people called in the middle of the night if something is not working. The RSE and the responsible scientist (RS) should work closely as the primary customer of the RSE is the RS. The RSE is the Scientists hands on the machine. Simply put the buck stops with the RSE. For new systems RSE is may have been the lead system engineer in which case they would coordinate the design, testing, installation, commissioning, and initial operation of a new diagnostic. Typically a lead engineer will evolve into a RSE until the system operates properly at which time a new RSE may be brought in to maintain operation.
- **FIDU and Trigger System (ITS):** The NIF facility has a completely passive 1053nm (1ω) & 527nm (2ω) 88ps timing pulse synced with the Main NIF Laser. This timing pulse is typically delivered to a diagnostic to allow absolute timing within the facility to an RMS jitter accuracy of <7ps. The Integrated Timing System is used to trigger all digitizers and other

instruments. It as a variable delay that can be selected electronically. It has a larger RMS jitter of ~25ps.

- **Data Transmission System:** Typically a high quality coaxial cable however for applications that require higher bandwidth optical system may be implemented. Currently 3 diagnostics operate using Mach-Zehnder Optical Modulator with a high speed Optical to Electrical Converter attached to the input of the Oscilloscope. The long distance of cabling required to send a signal from the Target Bay to the Diagnostic Mezzanine typically limits coaxial systems to less than 1GHz bandwidth. Optical Modulator based systems have the potential to exceed 20GHz total system bandwidth.
- **Integrated Computer Control System (ICCS & IBCs):** NIF has three major control systems that are needed for facility operation. The majority of system are connected through what is call the Integrated Computer Control System. This system talks to instruments and subsystem to facility all shot operations, countdown, device settings, etc. This system can have instruments that connect directly to the network or they can be connected through a front end processor (FEP). Within target diagnostics a separate slightly different architecture is implemented where all devices are connected directly to an Instrument Based Controller (IBC) this IBC is then in turn connected to the TD control network which is integrated into the ICCS control network. The physical connection between a digitizer and an IBC can be GPIB, Ethernet, RS232 or something similar. The software development group tasked with writing control code for instruments works closely with the ICCS group. The last control system is the Industrial Control System (ICS) which operates lower complexity higher risk systems such as vacuum, HVAC, gas/pressure systems. ICS is run using a distributed network of PLCs and generally does not communicate or interact with other control systems however many target diagnostics rely on the proper operation of ICS to operate.
- **Target Diagnostic Operators (TDOs):** This is the group of technicians that execute Dry-Runs, Rod Shots, and the System shot for Target Diagnostic Instruments. They perform physical setups including changing optical FIDU delay spools and RF attenuator changes. They run the ICCS/TD Control system that trigger and command digitizers to acquire data. They verify the functionality of the digitizer and instruments. They also perform minor troubleshooting during the shot cycle as necessary. They are the 1st line of defense if a system is not functioning properly. The RSE is responsible for maintaining their checklists and training on a given diagnostic.
- **Maintenance (CME):** This is the group that is tasked with maintaining a spare inventory for all electrical equipment in NIF. Additionally, they perform installation, maintenance, repairs, builds of chassis and all rack equipment. If a new system is being installed they will be the people to put it in the rack and if something breaks they replace it and have the broken equipment sent back for repair. They work closely with the RSE to make sure spares are available and that routine maintenance and calibration is performed.
- **Rack Space:** The NIF has 4 diagnostic mezzanines that were intended to provide a place outside of the target bay for diagnostic equipment to be installed and operated. This means that there is a finite amount of rack space of all of the equipment within NIF. What equipment is installed in what location and how efficiently it is packed have a large impact on the total number of diagnostics that can be fielded on the NIF.
- **Rack Cooling:** The tempered water system has a finite capacity to cool racks within NIF. In addition to rack space the heat load generated by power hunger equipment such as mult-gigahertz oscilloscopes limits the amount of equipment that can be placed in a given rack. Additionally heat can damage equipment, change the polarization of light in fibers, and

impact the stability of optics in NIF. Heat load in the racks must be understood and thought about during any system engineering analysis for equipment going into NIF racks.

- **Rack Power:** The Rack Power stakeholder is similar to the Rack Space and Rack Cooling stakeholder in that this stakeholder can limit how much equipment can be place in one rack. Additionally the impacts of ground loops, and noise transmitted to equipment epically digitizers through shared rack power circuits can have impacts on data quality and catastrophic impacts on equipment.
- **Data Archive:** This is the system that the raw digitized waveform is stored in immediately after a shot and kept for indefinitely. The analysis software does not interact directly with the output of the digitizer it pulls information from this system then processes it and displays it to the responsible scientists.

2.5.2 Passive Stakeholders

Passive Stakeholders are individuals, organizations, things, other systems, standards, protocols, procedures, regulations, which will influence the ability of the system to achieve its mission.

- **Nature (physics):** The physical phenomena that the system is ultimately trying to measure. This stakeholder can have
- **Responsible Scientist**: This is the individual tasked with determining what setting are needed
- **The Detector/transducer:** Typically this is a scintillator and PMT, Gas Cherenkov Cell and PMT, CVD-Diamond, X-ray Diode, Photo diode, or any other device that interacts with the physical phenomena that is being measure then ultimately turns it into an electrical signal
- **Data Analysis Systems (SAVI, Archive Viewer):** This is the data system that analyzes the raw data from the digitizer and performs any analysis to extract the information of interest from the waveform
- **Shot Setup/Configuration Software (CMT):** This is the data system that the responsible scientist interacts with to determine what setting and configuration shall be implemented for a given experiment
- **Digitizer Vendors:** These are the companies that build, maintain the digitizers, and respond to technical questions about the performance of their equipment
- **Target Diagnostic Management:** These are the individuals that evaluate the overall success of a diagnostic with input from the scientific community as well as decide how much resources (money, people, priority) a system should be given
- **Target Bay Radiation Environment:** The NIF Target Bay is a harsh environment for electronics due to high fluency of X-Rays, Neutrons, Gamma-Rays, Protons, and EMP. Because many diagnostics are required to obtain data during high yield shots where high prompt radiation will be present typical digitizers cannot be placed in the target bay. This is lead to the design of recording instrumentation behind thick concrete shield walls in diagnostic mezzanines and detectors close up to the target in the Target Bay or even in the Target Chamber. Because of this radiation the architecture of diagnostics had led to a requirement that digitizers be placed hundreds of data path (cables, fibers, etc) away from the detector they are tasked with reading.

2.6 Stakeholder Interview Summary

Stakeholders were interviewed based on their roll and system they are familiar with. Because some stakeholders are not people individuals responsible for those systems were interviewed wherever possible.

Stakeholders all were interviewed individually in their offices whenever possible. During each interview the stakeholder heard the same set of questions with an understanding that some questions may not apply. By covering the same set of question with every stakeholder they were given an opportunity to add insight to the problem even when it might have been outside of their primary roll. The questions were mostly to guide the conversation; the objective was to allow the stakeholder to speak freely about their needs without focusing on low level details.

The notes below cover the likes, dislikes, and key expectations for digitizer in the systems that they stakeholder understands and works with. The details of what they are trying to measure, how this is achieved, and the major challenges for the diagnostic are covered in the description of the diagnostics section 3.1. Typically each interview took twice the allotted time so the summary listed below is just the most important points that were uncovered.

2.6.1 Preliminary Interview Questions:

- Describe what you are trying to measure.
- Describe how fast this happens or how fast it is driven.
- Distinguish subsystems or subgroups that measure this currently.
- How does this become electrical? Specifically, what is the performance of the transducer?
- Describe what you don't like about your current digitizer system.
- Describe what you do like about you current digitizer system.
- If you had it to do over again what would you do differently?
- What are your top 3 requirements or more generally expectations from your point of view?

2.6.2 Target Diagnostic Management (Perry Bell):

Perry is responsible for all of Target Diagnostics Engineering. He also has 30 years of engineering experience in Laser ICF facilities, specifically diagnostics.

Dislikes:

- Product line lifetime 8 years with Tektronix
- Overhead for servicing is large (heavy, power hungry, lots of features not used)
- Price per channel is high

Likes:

- Good dynamic range, bit, temporal speed, sample rate
- Tektronix life extension programs
- Overvoltage protection on FTDs (they are self-protecting)

Key Expectations:

- Optimize cost per channel for a given performance
- Minimize servicing needs (inexpensive to maintain)

General Comments:

- Expect that in 10-15 years all scopes in NIF will be obsolete, develop a long term plan to address this
- Goal: fewest number of systems that cover the entire parameter space of NIF digitizer needs in TD
- Develop a simple set of digitizer solutions (4 or less) for all applications in NIF
- Plan for a 20 year time scale
- Reduce heat load and rack space

2.6.3 Scope Based Diagnostic Group Lead (Todd Clancy)

Todd is responsible for scope based diagnostics. He was the lead engineer for the nTOF diagnostic design and the former Responsible System Engineer (RSE) (see section 3.1 for a detailed description of these diagnostics).

Dislikes:

- Fixed attenuators
- Too many connections and failure points
- Fragile cables laying through racks (Handling is not robust)

Likes:

- Almost never fail
- Easy to use and do quick offline tests

Key Expectations:

- High performance in all areas, stability, timing, amplitude, robust, as good or better than current Tektronix scopes
- More effective bits per channel
- Reduce racks space
- Some level of in rack/mezzanine troubleshooting ability

General Comments:

- If it was done all over again, smaller digitizers, more effective bits, automatic attenuators, more cohesive latter attenuators minimize jumper cable length

2.6.4 Responsible System Engineer (Francisco Barbosa):

Francisco is the current Responsible System Engineer (RSE) for all nTOFs, pTOF, and DANTE (see section 3.1 for a detailed description of these diagnostics).

Dislikes:

- We don’t have a good way of maintaining instruments.
- We don’t a spare for each instrument

- All FTDs don’t have a good calibration method
- FTDs lack front panel control

Likes:

- Like the interface on the Tektronix scopes, its user friendly
- Generally likes Tektronix scopes because people are familiar with them and they are easy to learn.

Key Expectations:

- Minimize work to implement new diagnostics
- Maintainability: reduce RSE involvement/workload

General Comments:

- If it was done all over again, plan a long term maintenance plan, reduce down time, improve reliability, standardize equipment over all diagnostics, develop a way to do quicker repairs, and make them smaller.

2.6.5 Responsible System Engineer (Nathan Palmer):

Nathan is the current Responsible System Engineer (RSE) for FFLEX (see section 3.1 for a detailed description of these diagnostics).

Dislikes:

- Don’t understand what impact of DSP I the Tektronix scope
- Lack of over voltage protection. Blow out channels during troubleshooting
- Takes up too much rack space

Likes:

- Like the tools and the analytics in the display
- Easy to save traces to a flash drive
- Tektronix scopes are fairly easy to use
- They currently meet all the needs of the system

Key Expectations:

- Stability of time base (synchronous channels)
- Well calibrated amplitude
- Bandwidth and sample rate
- Reliability

General Comments:

- If it was done all over again, develop a more compact system, this one uses too much racks space.

2.6.6 Responsible System Engineer (Bob Chow):

2.6.7 Responsible Scientist (Jack Caggiano):

Jack is the Responsible Scientist (RS) for all nTOFs (see section 3.1 for a detailed description of these diagnostics).

Dislikes:

- Overdrive response of Tektronix scope
- Stitching channels together to obtain larger dynamic range
- The use of long cables
- The way the FIDU is injected into the signal path
- Bandwidth
- The number of reflections
- Takes up too much rack space

Likes:

- Dynamic range obtained with the current design
- The splitters are good quality 9be nice to fine tune them
- Attenuators are consistent
- We have lots of information about the scope

Key Expectations:

- Bandwidth and Oversampling (need significant oversampling)
- Effective Bits (need more true bits ie larger dynamic range and better SNR)
- Repeatability

General Comments:

- If it was done all over again, design it with more channels, more bandwidth, use electronic attenuators, build in measurement of system response on every shot, design a way to deal with the needs for high sensitivity and low sensitivity at the same time.
- Neither a like or a dislike that the current implementation uses scopes

2.6.8 Responsible Scientist (Mark Eckhart):

Mark is the one of the scientist working on the nTOFs (see section 3.1 for a detailed description of these diagnostics). He has over 30 years of experience with diagnostics.

Dislikes:

- The current approach to dealing with overdriven signals
- Bandwidth

- Extreme Linearity (not linear enough)
- Don't like the transducer (PMTs)
- Dynamic range and linear response
- Not characterized enough

Likes:

- Meets peek to tail precision of 1% very well (need 0.1% precision)
- High sample rate (10GSa/s)
- Reliability

Key Expectations:

- Digitizer response needs to be linear or understood well enough that it can be made linear
- Digitizer needs larger dynamic range, need 10 or 11 effective bits over 500MHz

General Comments:

- If it was done all over again, design it with more though about the yield and scattering sources near the detector. Also, we would consider racks of digitizers instead of scopes.
- Major challenge of the nTOFs is to measure tail to an accuracy of 0.1% relative to the peak

2.6.9 Responsible Scientist (Alastair Moore):

Alastair is the Responsible Scientist (RS) for DANTE 1 currently using Tektronix SCD 5000 and DANTE 2 currently using Greenfield FTD10000 (see section 3.1 for a detailed description of these diagnostics). Dante measures the hohlraum temperature on up to 18 channels per DANTE. The energy range is 100eV to 6keV for DANTE. Each diagnostic channel uses a single scope; both models of these scopes are vacuum tube based. DANTE was based on past diagnostics at other laser facilities and was one of the first to be installed in NIF.

Dislikes:

- Both types of scopes have a non-linear time base that requires periodic recalibration
- Very unreliable, each week one or more scopes breaks down, especially the SCD5000
- Not easy to maintain, it's very costly, labor intensive
- The way the FIDU is injected causes reflections
- The O/E for the FIDU is easily damaged by the signal

Likes:

- Dynamic range is quite good
- Overvoltage tolerance (1-2 KV has no impact on scope function)
- The current SNR is good (needs to be at least 100)

Key Expectations:

- Meeting the RMS requirements for the diagnostic
    - Absolute X-ray temperature

    - Absolute timing with respect to main NIF Laser (not currently achieved)
    - Cross timing from channel to channel
- Be reliable (not needing constant maintenance and reconfiguration)
- Maintain equivalent electrical performance of tube based system (not explicitly stated)

General Comments:

- An over voltage condition can occur if the wrong attenuation is installed or a X-ray filter breaks.
- Ben Hatch is currently performing a system engineering analysis on the scopes/digitizers for DANTE due to the relatively high cost of operating this diagnostic
- If it was done all over again, design it

2.6.10Control Systems (Jarom Nelson):

Jarom and his team of software engineers are responsible for the software interface and control systems that run all of the diagnostic instruments.

Dislikes:

- FTD10000 drop communication often. (Socket protocol on FTDs are more error prone)
- The scopes use lots of rack space and have a large heat load
- There are many capabilities in the scopes that we don't use
- GPIB is acceptable but requires a card to be installed in IBC

Likes:

- Internal removable HD (easily removed for classified operations)
- Scope interface for Tektronix scopes is simple and reliable
- Interface software is well established
- Tektronix scopes are compatible with NI visa library VXI-II
- Ethernet connection on scope does not require a 2^{nd} card in IBC
- Tektronix allows all full scope functionality through software interface

Key Expectations:

- Reliable interface (at least as good as current Tektronix scopes)
- Ability to swing easily (switch back and forth from classified to unclassed easily)
- Always provide a spare unit for software development

General Comments:

- Ideally the software interface would be identical to existing scopes so there would be no need for new software
- Long term sustainable and supported hardware is desirable

2.6.11 Maintenance and Spares (Clark Powell & Robert Mich):

Clark and Robert are responsible for all the electrical spare components for all of NIF including target diagnostics. They are tasked with maintaining a spares inventory of every component and performing installation and replacement tasks as needed.

Dislikes:

- Too many different types (it's not clear what overlap is allowed, and if software supports it)
- Need an overall through look at standardizing
- Spares for many systems when spares could be shared
- Spare plan is not shared across diagnostics
- Software tools for tracking maintenance/part number/installed location/last service date/etc are not well integrated (SMART, Glovia, CMT, ECMS, LoCoS don't talk well to one another)
- Spend too much time updating computer system with information (want a point of use data entry system, a single end user interface)
- Different types of software of different systems
- FTD10000 not reliable
- There is always at least 1 Tektronix scope needing repair
    - Takes 6-8 weeks to repair
    - Cost $6-13K for each repair
    - Repair between 10-30 per year
- Difficult to have a spare Tek scope because of so many different models and configurations
- Downtime is always longer than expected
- There are different part numbers in ECMS for the same scope

Likes:

- Everyone is familiar with the systems (basically it's an oscilloscope)
- Lack of knowledge about other systems/brands/designs (we understand what we are dealing with now "the devil you know is better than the one you don't"
- Work on the existing network
- Has onboard diagnostics

Key Expectations:

- Work with CME to develop spare/maintenance/calibration plan in the design phase and incorporate this plan with a larger NIF wide plan even if it means use equipment that is more powerful than the individual system requires
- Define the maintenance cycle in the design phase (procedures, SMART, etc) before it is fielded
- Develop sparing plan, maintenance plan, and calibration plan and who will do it

General Comments:

- Need to define boundary between groups (RSE vs. maintenance)
- Need to define maintenance cycle
- Need to develop a con-ops with a maintenance plan including who will do what and a calibration plan with procedures and define who will do it

- Spare plan across multiple diagnostics needs to be considered in the design phase

2.6.12 Integrated Timing System (Brad Golick):

Brad is responsible for the triggering system and the fiducial timing systems through NIF. Brad's team provides electrical triggers to each diagnostic with a digitizer and usually an optical fiducial marker that is timed into the entire laser system.

Dislikes:

- Adjusting the FIDU delay from shot to shot due to short record lengths
- The limited bandwidth and sample rate in scopes currently deployed (timing is usually an afterthought and higher bandwidth/sample rate would improve data quality on diagnostics that specifically measure relative timing ie laser to event)
- More thinking ahead about timing and triggering needs. There are too many different implementations on different diagnostics

Likes:

- Capture a waveform offline (outside of a shot)
- Reliable (70604 have a good time base)

Key Expectations:

- Stable trigger (minimize trigger jitter)
- Stable time base
- Higher vertical resolution than now (more ENOB)

General Comments:

- If this was done over again we should use fewer different models and use a more overdrive tolerant input

2.7 Expectations

The expectations of all stakeholders including individuals and other systems were captured with as little paraphrasing as possible. There were many common themes generally shared by individuals that had the same role with respect to the system.

Stakeholders familiar with Tektronix oscilloscopes were generally happy with their performance. They like the reliability, the relationship with the vendor, the time base, sample rate, ENOB, and the history we have had with them. Generally from a performance perspective

Stakeholders familiar with Greenfield FTD10000 were happy with some of the unique properties of their oscilloscopes such has over drive tolerance, extremely quick recover from overdrive conditions, and high number of effective bits (~13). They did acknowledge that they are expensive and do not scale well. Their major complaint was that they break often and require very frequent re calibration for their time base.

2.7.1 Key Expectations (sacred expectations, key acceptance criteria)

The top three key expectations from each interview were analyzed along with general comments about digitizer performance, likes, dislikes, and opinions about how an individual would do it over again. Although it was not explicitly stated in most interviews the most important expectations is that any new (or replacement) system would not compromise the performance the system currently has. This subtle point cannot be overlooked. If performance was to be reduced to meet other key expectations it is like that key stakeholders such as the Responsible Scientist would not accept the new design. This has happened in the past.

Rank	Key Expectation	Capability or Characteristic
1	Digitizers must have performance characteristics equal to or greater than the existing options	Capability
2	Digitizers architecture must be planned to meet the needs of the facility for the next 30 years	Capability
3	Digitizers should be as reliable as possible	Characteristic
4	Minimize the rack space and heat load	Characteristic
5	Minimize maintenance and calibration needs	Characteristic
6	Minimize the number of different types of digitizers (canned solution for future applications)	Characteristic
7	Digitizer must be commercially available	Characteristic

2.7.2 Goal Expectations

These are the "nice to have's" not the must be able to do type of expectations. It is valuable to identify these and make it explicit that these expiations may not be met however every reasonable effort will be made to achieve them.

- Obtain a single digitizer that can be used in all current and future applications
- Minimize cost per digitizer channel
- Minimize the cost per ENOB (effective number of bits)
- Digitizers should be scalable (able to build a small channel count or large easily)
- Greater than 8 ENOB @1GHz

3 System Operational Architecture

3.1 Existing (Reference) Target Diagnostic Digitizer Architecture

3.1.1 Neutron Time of Flight (nToF)

The nToF diagnostics measure neutron arrival time is directly related to the kinetic energy of the neutron. Generally the further from TCC they are the less bandwidth required. The nTOFs use two type of detectors Chemical Vapor Deposition Diamonds (CVD-Diamond) and Scintillators coupled to

Photomultiplier (or Photodiode) Tube. These diagnostics generally have very high precision requirements (error <0.1%) and large dynamic range (1:1e4).

3.1.1.1 DTLow & DTHi

- Detection Method: Conversion of neutrons to optical signal via Scintillator
- Transducer: Single Photomultiplier Tube (PMT) or Photo Diode (PD) (FWHM > 150ps)
- Distance from TCC: ~4.5m
- Signal Transmission System: 50m coaxial cable
- Total System Bandwidth: 200MHz
- Digitizer: 1x Tektronix DPO7104, 1Ghz, 8-bit, all 4 channels used to cover larger dynamic range

3.1.1.2 SpecA, SpecE, SpecSP, and SpecNP

- Detection Method: Conversion of neutrons to optical signal via Scintillator
- Transducer: 4 per diagnostic Photomultiplier Tube (PMT) and Photo Diode (PD) (FWHM > 150ps)
- Distance from TCC: >18m
- Signal Transmission System: 10m-50m coaxial cable depending on location
- Total System Bandwidth: 500MHz-1GHz (depending on configuration)
- Digitizer 1: 4x Tektronix DPO7104 &DPO 7254, 1GHz &2.5GHz, 8 bit, all 4 channels used to cover larger dynamic range
- Digitizer 2: Greenfield FTD10000, 6GHz, CCD coupled to Vacuum Tube Digitizer 13bit, single channel oscilloscope

3.1.1.3 IgHi

- Detection Method: Direct Charge collection via CVD-Diamond Detector
- Transducer: CVD Diamond (FWHM>150ps)
- Distance from TCC: >18m
- Signal Transmission System: 10m-50m coaxial cable depending on location
- Total System Bandwidth: ~1GHz – 2.5GHz (scope limited)
- Digitizer: 2x Tektronix DPO7104 &DPO 7254, 1GHz &2.5GHz, 8 bit, all 4 channels used to cover larger dynamic range

3.1.1.4 Bang Time (nTOF-BT) & Down Scatter Fraction (nTOF-DSF)

- Detection Method: Direct Charge collection via CVD-Diamond Detector
- Transducer: CVD Diamond (FWHM>150ps)
- Distance from TCC: >4m
- Signal Transmission System: Mach-Zehnder Interferometer Optical Modulator
- Total System Bandwidth: 2GHz
- Digitizer: 2x Tektronix DPO70604, 6GHz, 8 bit

3.1.2 Broadband, time-resolved x-ray spectrometer (DANTE)

There are two Dante spectrometer systems (DANTE1 and DANTE2) that take the same X-ray measurements for the upper and lower hemispheres. Each diagnostic has 18 channels covering the range of 50ev to 20keV. The main digitizer challenge of the SPBT diagnostic is a very high SNR >100 and the potential for detector bias breakdown sending full supply voltage into the digitizer (2kV).

- Detection Method: Direct Charge collection via CVD-Diamond Detector
- Transducer: XRD Diode (FWHM>150ps)
- Distance from TCC: ~6m
- Signal Transmission System: 50m coaxial cable depending on location
- Total System Bandwidth: <1GHz (cable limited)
- Digitizer 1: 18x Greenfield FTD10000, 6GHz, CCD coupled to Vacuum Tube Digitizer 13bit, single channel oscilloscope
- Digitizer2: 18x Tektronix SCD5000, 5GHz, 11 bit single channel oscilloscope

3.1.3 South Pole Bang Time (SPBT)

The South Pole Bang Time diagnostics measures temporally resolved 9-12keV X-rays generated within the hohlraum. The main digitizer challenge of the SPBT diagnostic is a very high SNR >100 and the potential for detector bias breakdown sending full supply voltage into the digitizer (2kV). Upgrading the data transmission system from coaxial cables to an optical MZ based system would lead to detector limited bandwidths.

- Detection Method: Direct Charge collection via CVD-Diamond Detector
- Transducer: CVD Diamond (FWHM>150ps)
- Distance from TCC: ~2m
- Signal Transmission System: 50m coaxial cable depending on location
- Total System Bandwidth: 6GHz (scope limited)
- Digitizer 1: 4x FTD10000, 6GHz, CCD coupled to Vacuum Tube Digitizer 13bit, single channel oscilloscope
- Digitizer2: 1x Tektronix DPO70604, 6GHz, 8 bit

3.1.4 Gamma Reaction History (GRH)

The Gamma Reaction History Diagnostic measures high energy gamma rays in the range of 2.9MeV to 20MeV by way of a Compton scattering in an Aluminum converter foil to produce Compton electrons, which recoil into a gas-filled cell generating broadband Cerenkov light. This light is detected using photomultiplier tubes and then sent through a Mach-Zhender Optical data transmission system. The primary challenge of this system is bandwidth (>10GHz)

- Detection Method: Compton scatter electrons generate light Cherenkov in a gas cell.
- Transducer: 4 per diagnostic Photomultiplier Tube (PMT) and Photo Diode (PD) (FWHM > 50ps)
- Distance from TCC: >6m
- Signal Transmission System: Mach-Zehnder Interferometer Optical Modulator
- Total System Bandwidth: ~6GHz (detector limited)
- Digitizer: 2x Tektronix DPO71254 & DPO 7104, 12GHz &1GHz, 8 bit, all 4 channels used to cover larger dynamic range

3.1.5 Filter Fluorescer Diagnostic (FFLEX/FFLEX -TR)

FFLEX measures the absolute radiant hard x-ray power vs time in ten spectral bands (18 keV to 400 keV). This diagnostic uses a series of scintillators and ten Hamatsu Photomultiplier Tubes.

- Detection Method: Scintillator

- Transducer: 10 Photomultiplier Tube (PMT))
- Distance from TCC: >6m
- Signal Transmission System: Mach-Zehnder Interferometer Optical Modulator
- Total System Bandwidth: <1GHz (detector limited)
- Digitizer: 5x Tektronix DPO7254 & 2GHz, 8 bit, all 2 channels used to cover larger dynamic range

3.1.6 Additional Target Diagnostics using Digitizers

The following diagnostics are included for completeness however due to limited scope

- FABS (Full Aperture Back Scatter)
- Near Backscatter Image (NBI)
- Electromagnet Power (EMP)
- System Generated Electromagnet Power (SGEMP)
- Diagnostic Instrument Manipulator based Framing Camera Gate Pulse Monitors Monitor

3.2 As Is Operational Scenarios

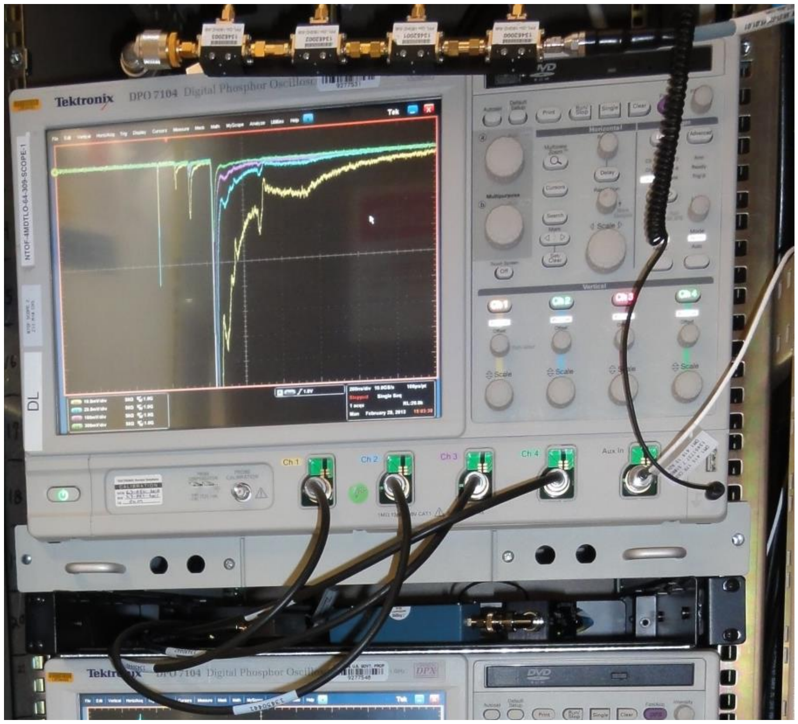
Currently there are two types of digitizers implemented in NIF CRT oscilloscopes and digital oscilloscopes. There are two types of CRT oscilloscopes, obsolete Tektronix SCD5000 and Greenfield FTD10000. All of the digital oscilloscopes are from Tektronix. Lower bandwidth versions are all DPO7000 series with bandwidths of 1GHz, 2 GHz, and 2.5GHz. Higher bandwidth scopes are all DPO70000 series with bandwidths of 4GHz, 6GHz, and 12.5GHz, (versions A, B, and C with and without 2SR enhanced sample rate option). Older TDS series scopes have generally been phased out due to issues with their time base.

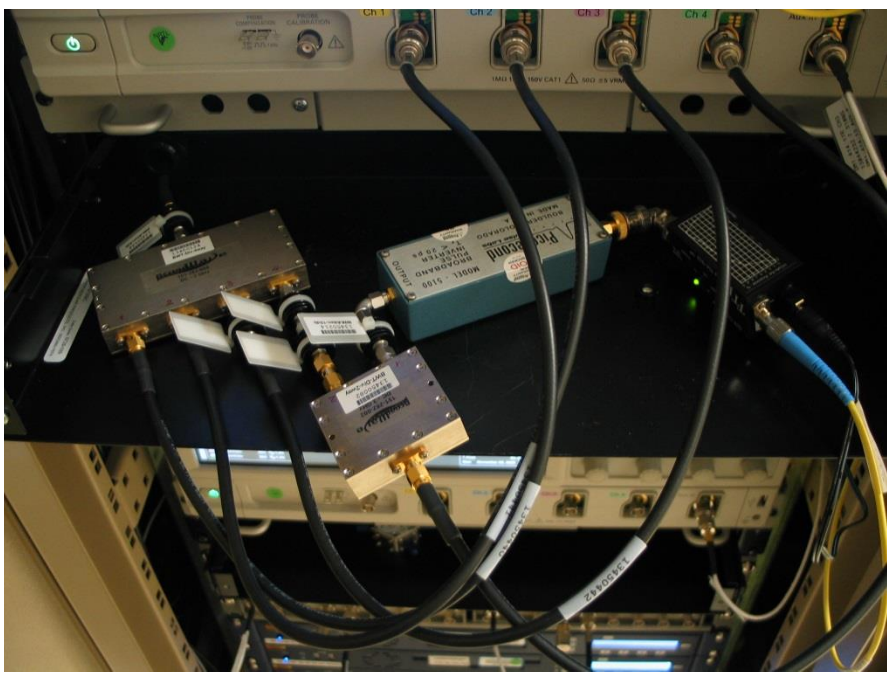
3.2.1 Tektronix Oscilloscopes

The following sections show some images of the Tektronix oscilloscopes as installed in NIF.

3.2.1.1 Tektronix Oscilloscopes <4GHz (DPO7000 series)

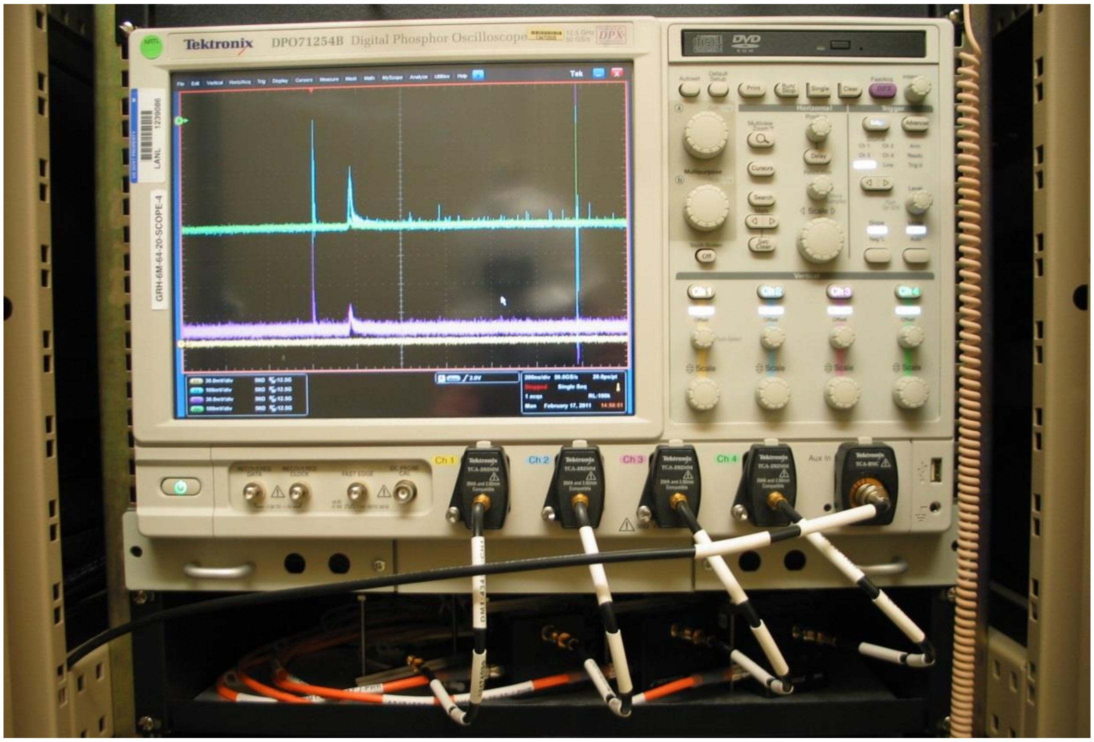
A single large TimesMicrowave LMR600 coaxial cable is typically routed a long distance from the detector to the oscilloscope where the input is spread over multiple channels to increase the dynamic range and SNR. Line insertable attenuators splitters and FIDU signals are all mixed in at the oscilloscopes.





3.2.1.2 Tektronix Oscilloscopes >4GHz (DPO70000 series)

Systems with higher bandwidth utilize a series of O/E converters to change an optical signal typically generated by a Mach-Zhender Modulator close to the detector. Additional rack space for the O/E is required. The DPO71254 shown below typically consumes 400+ watts of power continuously and internal temperature in the racks where multiple scopes are mounted can be as high as 112F.



3.2.2 SCD5000s and FTD10000

The Greenfield FTD10000 shown below occupies less rack space than SCD5000s and Tektronix scopes however they are single channel devices. Additionally they have none of the front panel functionally that the Tektronix scopes have. FTD10000s have a limited record length that requires operators to manually install and remove FIDU delay spools from shot to shot.

3.3 To Be Operational Scenarios New Envisioned Target Diagnostic Digitizer Architecture

Chassis based digitizers shown below can house over 68 digitization channels in a 4U rack space. Applications that do not require as many channels or higher bandwidth will utilize conventional digital oscilloscopes

4 Constraints and Drivers

4.1 Drivers

- Reliability: SCD5000s and FTD10000s have very poor reliability and require frequent calibration
- Operating Cost:
  - Repair costs for SCD5000 and FTD10000
  - Calibration costs for SCD5000 and FTD10000
  - Manual channel reconfiguration and
  - Manual delay spool installation and reconfiguration
- Need for Long term plan
- Need to reduce development time for future diagnostics
-

4.2 Constraints

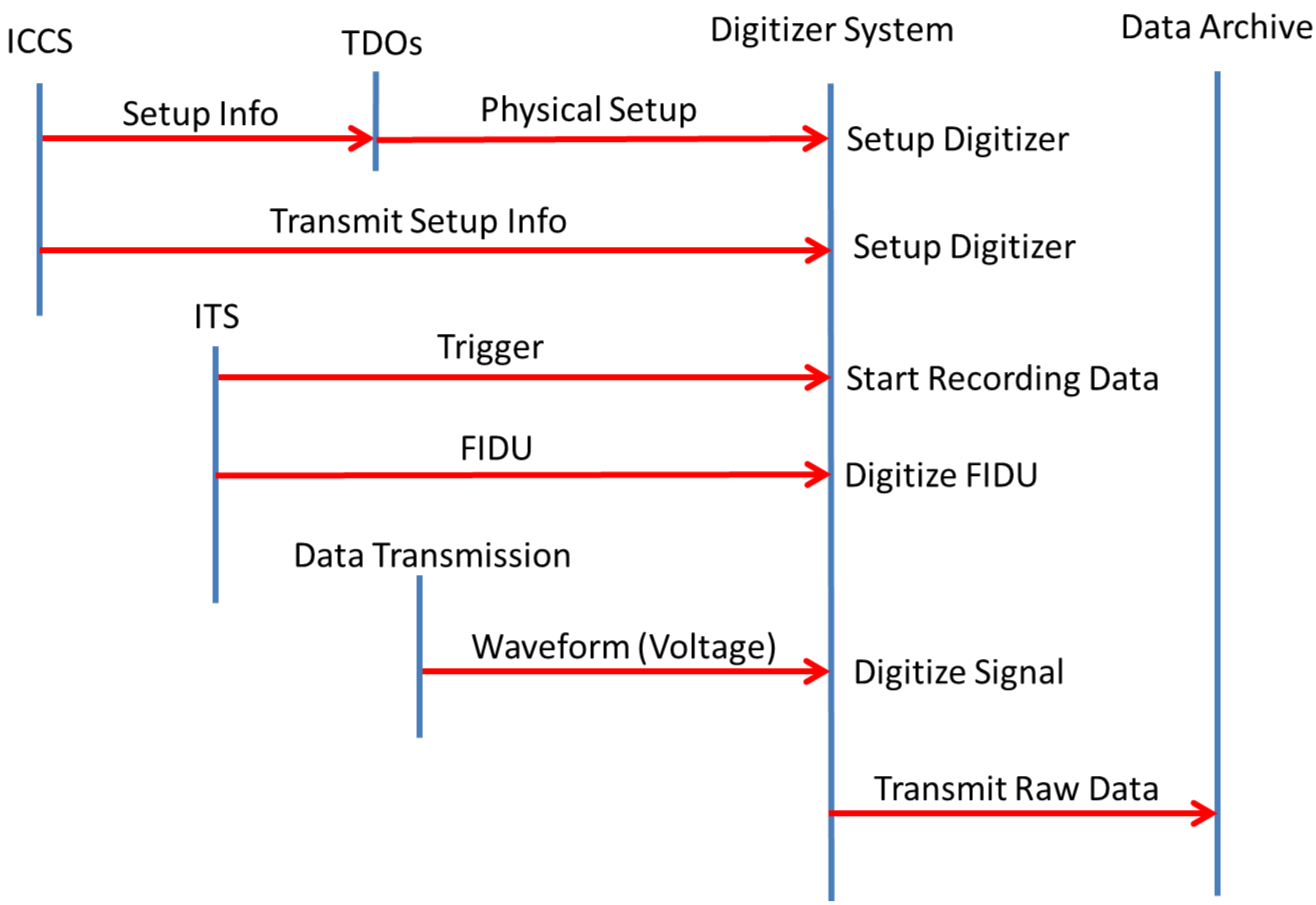
- Design Safety Standards of NIF
- Budget
- Total mezzanine rack space
- Rack heat load capacity
- Rack power supply capacity
- Radiation Environment of the Target Bay
- Location of Diagnostics
- Commercial availability of digitizers in a given form factor
- Lab culture

5 Operational Scenarios (Use Cases)

5.1 As Is Operational Scenario for the Current System

5.1.1 Primary Operational Scenario (Use Case #1)

The primary use case is a system shot on NIF. The swim chart below shows the process for setup, triggering, data acquisition and data transmission for currently fielded systems.



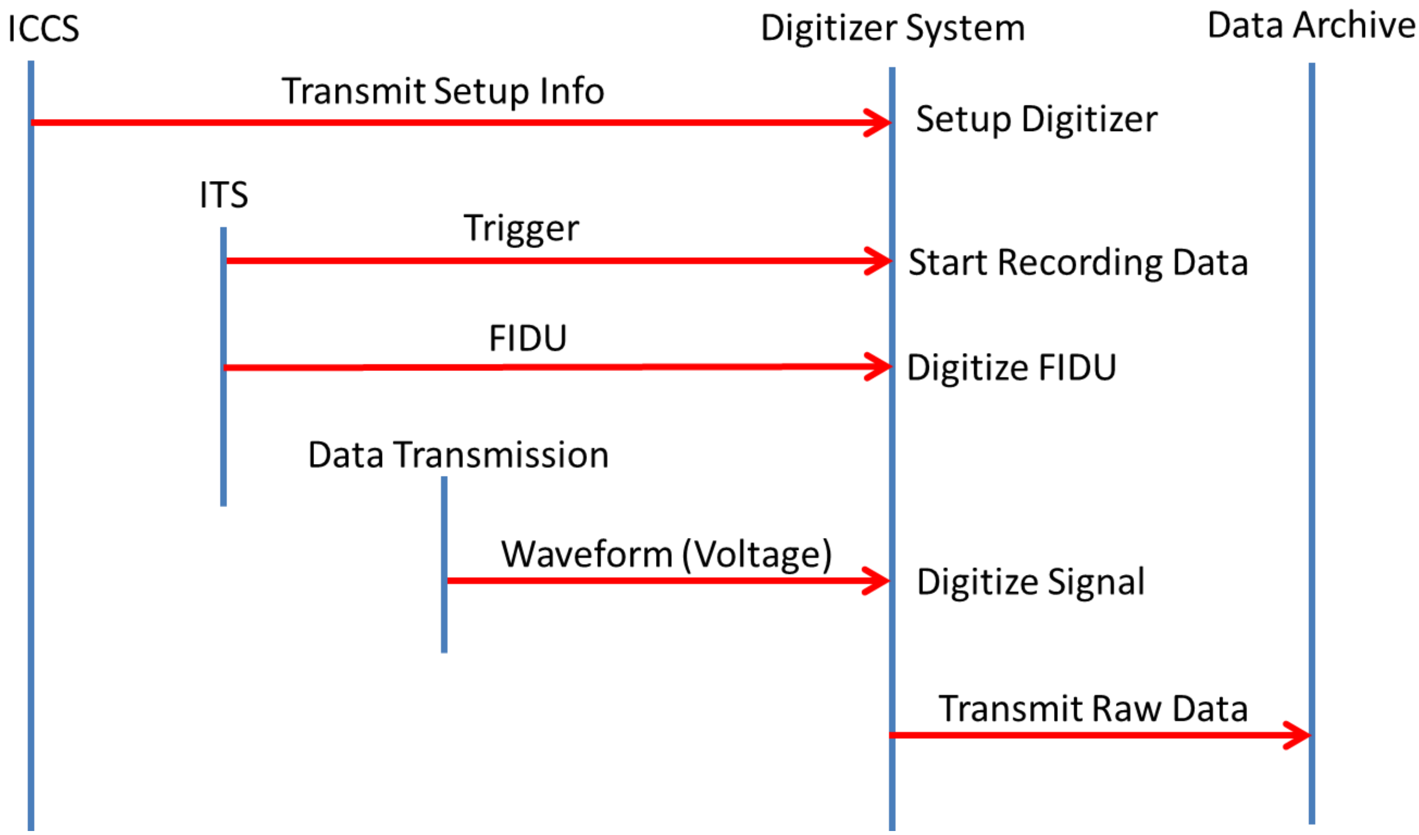
5.2 To Be Operational Scenario for the envisioned System

The to be operational scenario is very similar to the current implementation however setup steps have been removed due to the use of input protection circuits, system integrated automated attenuators, and longer record lengths of digital oscilloscopes.

5.2.1 Primary Operational Scenario (Use Case #1)

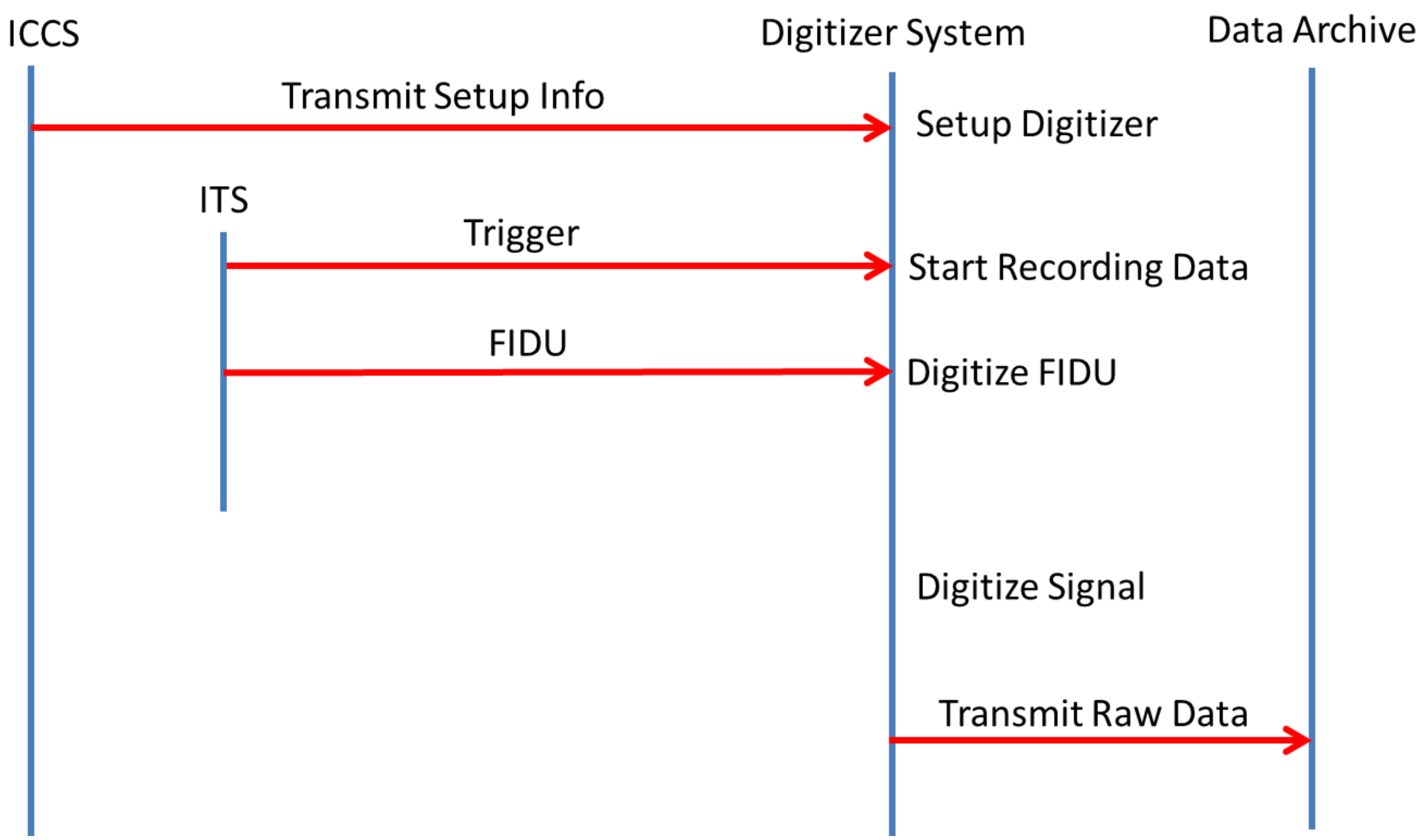
5.2.1.1 Use Case 1a System Shot

The proposed system shot use case follows the current implementation without the need for TDOs (Target Diagnostic Operators) to perform manual configurations.



5.2.1.2 Use Case 1b Rod Shot or Dry-Run

To insure that a diagnostic is ready to take data on the system shot dry-runs and rod-shots (integrated system triggering without main laser firing) are performed. The swim chart below show this use case.

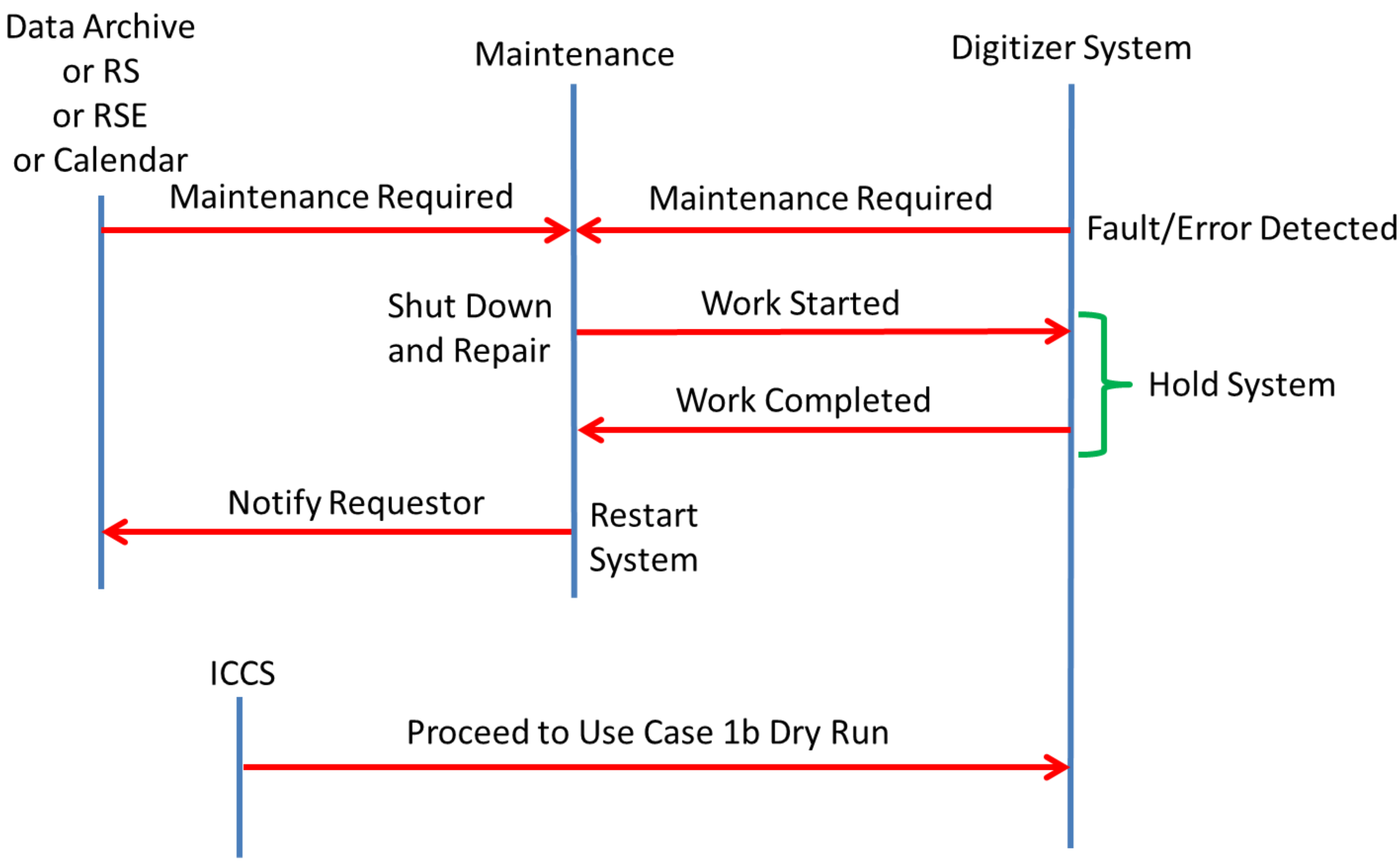


5.2.2 Secondary Operational Scenario (Use Case #2)

Maintenance and calibration operations are required on any system. In these situation the active stakeholders change from those in normal shot operations to the RSE (Responsible System Engineer) and maintenance personnel.

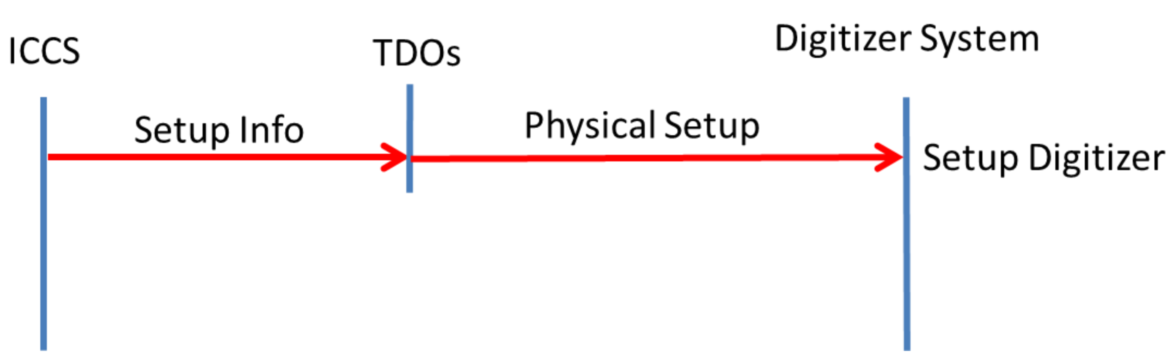
5.2.2.1 Use Case 2 Planned or Unplanned Maintenance

In the use case shown below several stakeholders can initiate the maintenance request. The RS (Responsible Scientist) can determine that there is a problem with the data and the system needs to be inspected, repaired, or a component replaced. The RSE (Responsible System Engineer) or the CME (Controls Maintenance Engineering) may have periodic maintenance or calibration plans that they execute on a schedule or when shot data appears out of specifications. Additionally the system may alert the operators that it is in need of repair or maintenance. The repair or maintenance process then involves shutting down the system performing work, notifying requiting agent that the work is complete and proceeding to a dry-run to verify system functionality. This use case is virtually identical to the existing architecture however additional self-test diagnostic and calibration capabilities are present in newer oscilloscopes which should be implemented in all future systems.



5.3 Operational Scenarios Comparison

In the "to be" system architecture operators do not have physically reconfigure any part of the system. This will save many hours of operator time and allow the facility to run more diagnostics with the same personnel. Physical setup tasks include attenuator changes, scope input changes, delay spool changes, and all the documentation associated with any manual change (this typically doubles the time required to perform a task).

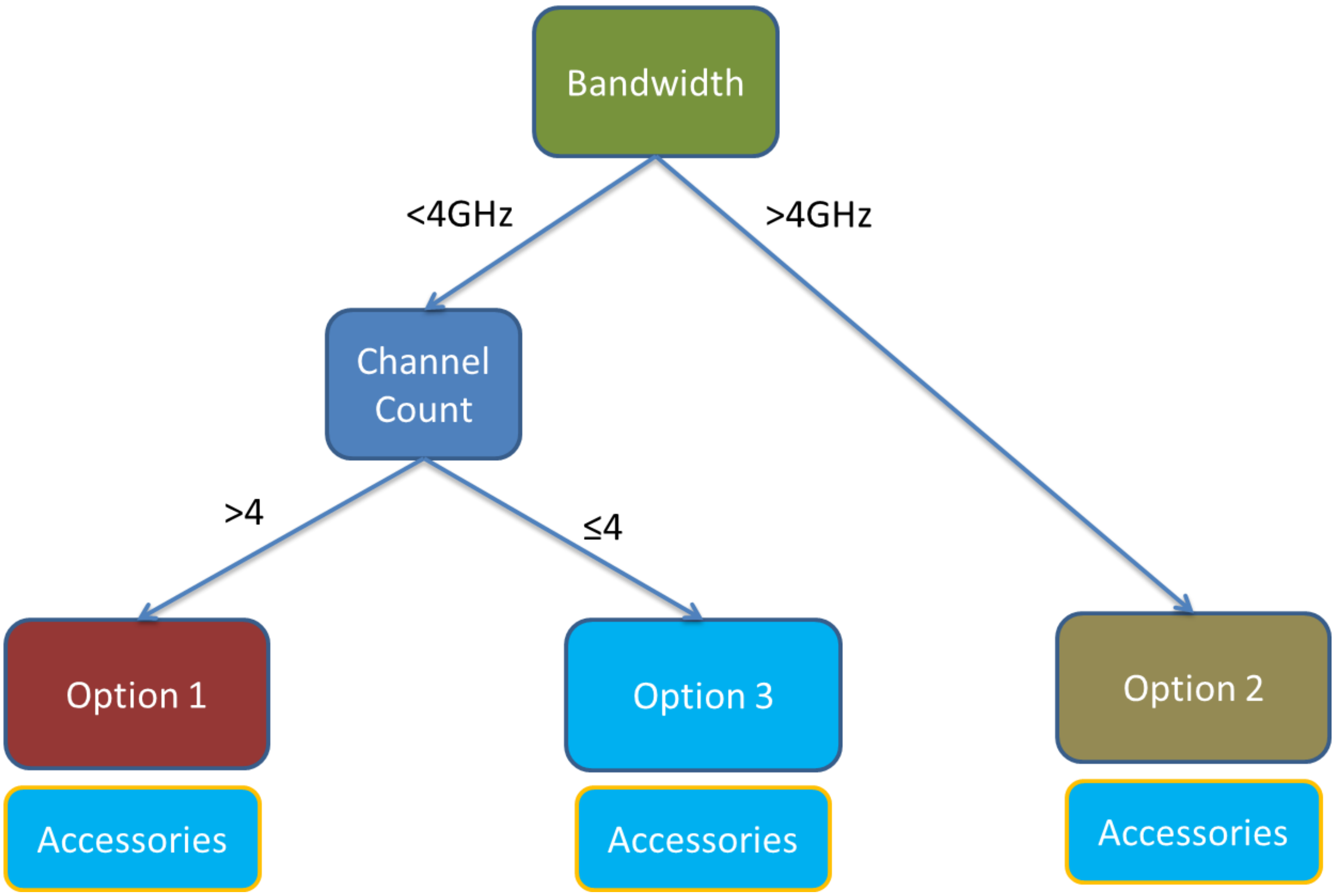


6 Implementation Concepts

6.1 Application Driven Digitizer Selection

Based upon the sacred (key) expectations covered in section 2.7.1 no single digitizer architecture can cover all current needs; moreover it is even more unlikely that any single architecture could cover all future applications. In an attempt to minimize the number of different architectures three separate architectures emerge. The first is high precision and high channel count. This architecture will rely on a chassis based digitizers. The second is high bandwidth applications. This architecture is driven by the need for higher system bandwidths (≥5GHz). The third is based on the current digitizer architecture but it is limited to applications where only a single oscilloscope is required (channel count ≤4). The rack space issues created by the high channel count diagnostics are a function on the poor scaling of the current architecture. If high channel count is not required the current architecture meets all other expectations. The "Additional Accessories & Options" is meant to deal with application where a FTD10000 or SCD5000 would have been used. The capabilities (over voltage protection, fast recovery after clipping etc) that these oscilloscopes provided can be implemented by accessories that are placed on the input to one of the other three architectures.

During the initial analysis of stakeholder interviews it a solution concept regarding "pizza box" low profile digitizers looked very promising. Simply put stakeholders would like to have 1U high versions of the Tektronix scopes currently available and used widely in NIF. This has been a desire for at least 7 years through out NIF and numerous conversations with Tektronix have always ended with them being unable to build such a unit because the market for it is too small. Other vendors such as Keysight make low profile digitizers which are covered in the following sections however the performance specifications of these units do not match the needs of current or future systems so this option was excluded. A Pugh chart analysis of the different options for high channel count high precision is shown in section 7.3. Another promising option that was considered is standalone compact digitizers again these options could not meet the performance requirements. If Tektronix was willing to package existing and future oscilloscopes in a low profile rack mountable versions the results of this system engineering analysis would likely be different. Additionally new models and versions of equipment are continuously being released. In section 11 recommendations about contacting vendors to stay up to date on future models and pass on information about our needs are made.


Bandwidth
<4GHz
>4GHz
Channel Count
>4
≤4
Option 1
Option 3
Option 2
Accessories
Accessories
Accessories

1. High Precision and/or High Channel Count:

- High Dynamic Range
- High SNR (≥1000)
- Medium bandwidth (<4GHz)
- High Channel Count (16+)

Current Applications:

- nTOF all
- SPBT
- FFLEX
- DANTE

2. High Bandwidth 6-45GHz:

- Medium Dynamic Range
- Medium SNR
- High bandwidth (requires Mach Zehender)
- High Channel Count (≥4)

Current Applications:

- GRH
- nTOF-BT/DSF
- GCD
- DIM Monitor

3. Low Channel Count Medium Precision

- Medium Dynamic Range
- Medium SNR
- Medium to High bandwidth (up to 12GHz)
- Low channel Count ≤4

Current Applications:

- Some nTOFs

Additional Accessories & Options:

- Clipper Protection Circuit
- Fast RF Switches on Input
- Log Amp/Attenuator
- Electronic Attenuators
- Optical Data Transmission & Multiplexing
- Temporary Installations

Applications:

- Variable

6.2 Digitizers Industry Analysis

The following sections cover a partial snapshot of what digitizers are available currently from major and some minor brands. There three major categories, chassis based, high bandwidth, and general purpose oscilloscopes are covered. Additionally sections on low profile digitizers and standalone units are covered. If available performance metric such as bandwidth, channels, sample rate, bits, and input voltage are summarized with each device. The purpose of this section is to give a feel for where the industry is and guide a decision on the best solution space. The test plan and analysis needs stated in section 11 cover the next steps for organizing this information to derive a conclusion on the best solution. A brief introduction to the technology needed for the input protection accessories and options is also covered in section 6.3.

6.2.1 Chassis Based Digitizers (High Precision and/or High Channel Count)

In this section an overview of available cards for VME, PXI, and AXI are discussed. NIM Crate options have been excluded due to the lack of available and relative age of this backplane/chassis technology.

6.2.1.1 VMEbus (Versa Module Europa bus)

VMEbus is a computer bus standard, widely used for many applications and standardized by the IEC as ANSI/IEEE 1014-1987. It dates back to 1979 and is fairly ubiquities. Many Front End Processors (FEPs) in NIF for other systems use VME chassis and cards.

6.2.1.1.1 Keysight (formally part of Agilent Technologies formally HP)

Keysight is a major American producer of test equipment including digitizers and oscilloscopes with HP dating back to at least the 1960s.

6.2.1.1.1.1 U1083A-002 Acqiris SVM1500 High-Speed 6U

- Analogue Bandwidth: 3GHz
- Sample Rate: 2GSa/s
- Bits: 10
- ENOB: 6.9 @ 1GHz
- Number of Channels at full resolution:2
- Input Voltage: ± 0.5 V
- Total Samples:
- Other Notes:
- Cost:

6.2.1.1.2 CAEN (Costruzioni Apparecchiature Elettroniche Nucleari S.p.A)

CAEN is an Italian nuclear physics test equipment company dating back to 1979.

6.2.1.1.2.1 V1742, V1743, VX1742, VX1743

- Analogue Bandwidth: >0.5GHz
- Sample Rate: 5GSa/s (3.2GSa/s for V1743)
- Bits:12
- ENOB: unlisted
- Number of Channels at full resolution:32+2 (16 for V1743)
- Input Voltage: ± 1 V (±2.5V for V1743)
- Total Samples: 1024 per channel
- Notes: 200ns record length for V1742, noise level 0.7mV RMS for V1743
- Cost:

6.2.1.1.2.2 V1761, VX1761

- Analogue Bandwidth: 1GHz
- Sample Rate: 4GSa/s per channel
- Bits:10
- ENOB: unlisted
- Number of Channels at full resolution:2

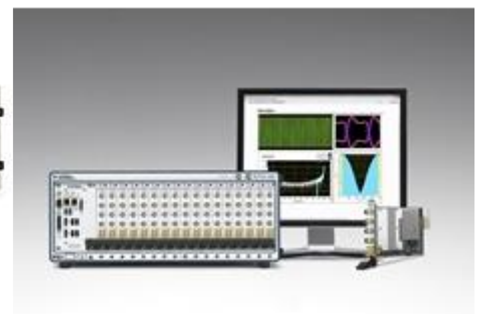
- Input Voltage: ± 1 V

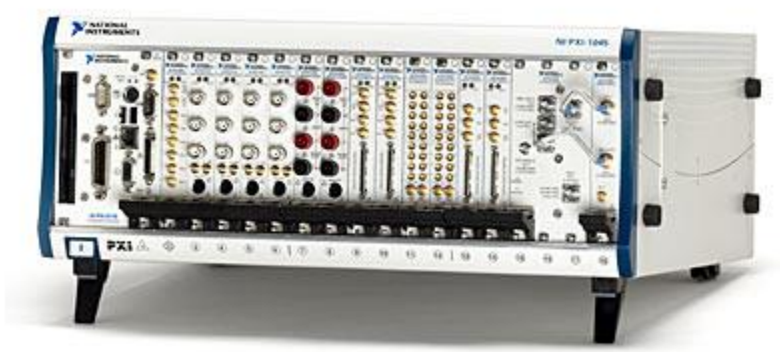
6.2.1.2 Acquitek & Struck SIS3305

- Bandwidth: 2 GHz
- Number of Channels:2/4/8 channels
- Bits: 10
- Sample Rate: 5 GS/s/2.5 GS/s/1.25 GS/s per channel

6.2.1.3 *PXI/PXIe (PCI eXtensions for Instrumentation)*

PXI is a modular instrumentation platform originally introduced in 1997 by National Instruments based on CompactPCI. PXI is promoted by the 54-member PXI Systems Alliance. Over a thousand modules for a variety of purposes are available. Typical chassis are 4U high and can contain up to 18 modules.





6.2.1.3.1 Keysight

6.2.1.3.1.1 Keysight M9210A

- Bandwidth: 1.4GHz
- Bits: 10
- Vertical Scale (full): 0.05V to 5V
- Sample Rate: 4GSa/s for 1Ch, 2 GS/s for 2Ch
- Number of channels: 2
- Number of channels at full sample rate: 1
- Price: $13k

6.2.1.3.1.2 Keysight M9211A

- Bandwidth: 3GHz
- Bits: 10
- Vertical Scale (full): 0.05V to 5V
- Sample Rate: 4GSa/s for 1Ch
- Number of channels: 1
- Number of channels at full sample rate: 1
- Price: $13k

6.2.1.3.2 National Instruments

NI is an American company founded in 1976 focused on automated test equipment and instrument control. They are the company behind LabView and PXI. They have a partnership with Tektronix to produce some of their higher bandwidth PXI digitizers.

6.2.1.3.2.1 National Instruments NI PXIe-5186

- Bandwidth: 5GHz
- Bits: 8
- Vertical Scale (full): -0.5 to +0.5
- Sample Rate: 12.5GSa/s for 1Ch, 6.25 GS/s for 2Ch
- Number of channels: 2
- Number of channels at full sample rate: 1
- Price: $45k

6.2.1.3.2.2 National Instruments NI PXIe-5185

- Bandwidth: 3GHz
- Bits: 8
- Vertical Scale (full): -0.5 to +0.5
- Sample Rate: 12.5GSa/s for 1Ch, 6.25 GS/s for 2Ch
- Number of channels: 2
- Number of channels at full sample rate: 1
- Price: $32k

6.2.1.3.2.3 National Instruments NI PXIe-5162

- Bandwidth: 1.5GHz

- Bits: 10
- Vertical Scale (full): -0.5 to +0.5
- Sample Rate: 5GSa/s for 1Ch, 2.5GSa/s for 2Ch, 1.25 GS/s for 4Ch
- Number of channels: 4
- Number of channels at full sample rate: 1
- Price: $19k

6.2.1.3.3 Aeroflex:

6.2.1.3.3.1 Aeroflex 3030 Series RF Digitizers (DDC)

Not Covered due to questions about Digital Down Converting Performance

6.2.1.3.3.2 Aeroflex 3070A PXI High Performance RF Digitizer (DDC)

Not Covered due to questions about Digital Down Converting Performance

6.2.1.3.4 Other PXI Instruments

- M9168C PXI Programmable Step Attenuator Module, DC to 26.5 GHz
- M9404A PXIe Optical Receiver
- M9405A PXIe RF Amplifier
- M9404A PXIe Optical Receiver

6.2.1.4 AXIe (AdvancedTCA Extensions for Instrumentation and Test)

AXIe is a modular instrumentation standard created by Aeroflex, Agilent Technologies, and Test Evolution Corporation. AXIe was launched in 2009 it is a fairly new standard that offers some advantages over PXI yet it does not have as many modules and instruments available.

6.2.1.5 Keysight M9703 (DDC)

- Bandwidth: 2GHz
- Bits: 12
- Vertical Scale (full): 2V
- Sample Rate: 3.2GSa/s for 4ch 1.6GSa/s for 2ch
- Number of channels: 8
- Number of channels at full sample rate: 4
- Price: $74k

6.2.1.6 Guzik ADC 6000 Series

- Bandwidth: 13GHz@1ch, 8GHz@2ch, 4GHz @4ch
- Bits: 8
- Vertical Scale (full): 2V
- Sample Rate: 40Gs/s for 1ch 20GSa/s for 2ch, 10GSa/s for 4ch
- Number of channels: 4
- Number of channels at full sample rate: 1

6.2.2 Oscilloscopes (High Bandwidth 6-45GHz)

6.2.2.1 Tektronix DPO70000 Series

- Bandwidth: 4 - 23GHz (2 channels @33GHz)
- Bits: 8
- Vertical Scale (full): Variable 0.01V to 10V
- Sample Rate: 50GSa/s
- Number of channels at full sample rate: 4
- Rack space: 7u?
- Price: $40k - $285k

6.2.2.2 Keysight

6.2.2.2.1 Infiniium DSO90000 series

- Bandwidth: 20 - 33GHz
- Bits: 8
- Vertical Scale (full): Variable 0.01V to 10V
- Sample Rate: 40GSa/s (2@80GSa/s)
- Number of channels at full sample rate: 4
- Rack space: 7u?
- Price: $177k - $285k

6.2.2.2.2 Infiniium DSAZ and DSOZ Series

- Bandwidth: 50 - 63GHz
- Bits: 8
- Vertical Scale (full): Variable 0.01V to 10V
- Sample Rate: 80GSa/s (2@160GSa/s)
- Number of channels at full sample rate: 4
- Rack space: 7u?
- Price: $177k - $285k

6.2.2.3 Teledyne LeCroy

6.2.2.3.1 WaveMaster 8 Zi-A Modular Oscilloscope

- Bandwidth: 4 - 30GHz
- Bits: 8
- Vertical Scale (full): Variable 0.01V to 10V
- Sample Rate: 40GSa/s (2@80GSa/s)
- Number of channels at full sample rate: 4
- Rack space: 7u?
- Price: ?

6.2.2.3.2 LabMaster 9 Zi –A Modular Oscilloscope

- Bandwidth: 13 - 45GHz
- Bits: 8
- Vertical Scale (full): Variable 0.01V to 10V
- Sample Rate: 50GSa/s
- Number of channels at full sample rate: 4-80 (depending on configuration)
- Rack space: 20u?
- Price: $115k - $1M?

6.2.2.3.3 LabMaster 10 Zi Modular Oscilloscope

- Bandwidth: 20 - 65GHz
- Bits: 8
- Vertical Scale (full): Variable 0.01V to 10V

- Sample Rate: 80GSa/s (up to 160GSa/s)
- Number of channels at full sample rate: 4-80
- Rack space: 20u?
- Price: $200k - $1M?

6.2.3 Oscillоscopes (Low Channel Count Medium Precision)

6.2.3.1 Tektronix

Tektronix is a American oscilloscope and test equipment company that recently took over Picosecond Pulse labs. They have been producing oscilloscopes since the late 1940s

6.2.3.1.1 DSO7000 Series

- Bandwidth: 0.5-3.5GHz
- Bits: 8
- Vertical Scale (full): Variable 0.01V to 10V
- Sample Rate: 10GSa/s, 40GSa/s
- Number of channels at full sample rate: 4@10GSa/s, 1@40GSa/s
- Rack space: 7u
- Price: 18k-40k

6.2.3.2 Keysight

6.2.3.2.1 Infiniium S-Series high-definition oscilloscope DSO9404A

- Bandwidth: 1.5-4GHz
- Bits: 8
- Vertical Scale (full): Variable 0.01V to 10V
- Number of Channels: 4

- Sample Rate: 10GSa/s, 20GSa/s
- Number of channels at full sample rate: 4@10GSa/s, 2@20GSa/s
- Rack space: 6u?

6.2.3.2.2 DSOX3104T Oscilloscope

- Bandwidth: 0.1-1GHz
- Bits: 8
- Number of Channels: 4
- Vertical Scale (full): Variable 0.01V to 10V
- Sample Rate: 2.5GSa/s, 5GSa/s
- Number of channels at full sample rate: 4@2.5GSa/s, 2@5GSa/s
- Price: 3k-15k
- Rack space: 6u?

6.2.3.3 Teledyne LeCroy

LeCroy is one of the three the largest manufacturer of oscilloscopes in the world along with Tektronix and Keysight. The company was founded in 1964 and is known for some of the first digital oscilloscopes in the world and some of the highest sample rate oscilloscopes currently commercially available.

6.2.3.3.1 WaveSurfer 10 Oscilloscope

- Bandwidth: 1GHz
- Bits: 8
- Vertical Scale (full): Variable 0.01V to 10V
- Sample Rate: 10GSa/s, 5GSa/s
- Number of channels at full sample rate: 2@10GSa/s, 4@5GSa/s
    - (4@10GSa/S with WS10-ADT option)
- Rack space: 6u?

- Price: $10k

6.2.3.3.2 HDO4000 / HDO4000-MS High Definition Oscilloscopes
- Bandwidth: 200 MHz - 1 GHz
- Bits: 12
- Sample Rate: 2.5GSa/s
- Number of channels: 2, 4

6.2.3.3.3 WaveRunner 6 Zi Oscilloscopes
- Bandwidth: 400 MHz - 4 GHz
- Bits: 8
- Sample Rate: 40GSa/s
- Number of channels: 4

6.2.3.3.4 HDO6000 / HDO6000-MS High Definition Oscilloscopes
- Bandwidth: 350 MHz - 1 GHz
- Bits: 12
- Sample Rate: 2.5GSa/s
- Number of channels: 4

6.2.3.3.5 HDO8000 High Definition Oscilloscopes
- Bandwidth: 350 MHz - 1 GHz
- Bits: 12
- Sample Rate: 2.5GSa/s
- Number of channels: 8

6.2.3.4 Rohde-Schwarz
Rohde-Schwarz is a German company in a variety of high tech fields including electronic test equipment. They offer a limited number of oscilloscopes and network analyzers.

6.2.3.4.1 R&S RTO1044, RTO1024, RTO1014, RTO1004

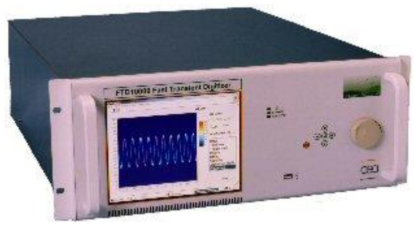
- Bandwidth: 0.6-4GHz
- Bits: 8 (>7.0 ENOB @3dB bandwidth)
- Vertical Scale (full): Variable 0.01V to 10V

- Sample Rate: 20GSa/s, 10GSa/s
- Number of channels at full sample rate: 2@20GSa/s, 4@10GSa/s
- Rack space: 6u?
- Overvoltage Limit: 5V RMS

6.2.3.5 Greenfield

Green field is a French company known to be currently the only company that manufactures and supports tube based oscilloscopes. They additionally produce several low profile digitizers.

6.2.3.5.1 FTD10000:



- Bandwidth: 7GHz Transient Digitizers (13GHz with equalizer)
- Bits: 13 (vertical bits)
- Vertical Scale (full): Fixed 5V
- Sample Rate: 10bits (depending on sweep speed)
- Number of channels at full sample rate: 1 (single channel device)
- Rack space: 4u
- Overvoltage Limit: 2kV
- Cost: ~$80k

6.2.4 Stand Alone Compact Digitizers

6.2.4.1 USB Based Picoscope 6507

- Bandwidth: 1GHz
- Bits: 8
- Vertical Scale (full): 0.2V +/-100mV fixed
- Sample Rate: 5Gsa/s, 2.5GSa/s, 1.25GSa/s
- Number of channel: 4@5Gsa/s, 2@2.5GSa/s, 4@1.25GSa/s
- Rack space: <1u
- SNR: 58.5dB
- Maximum Input: 2V (DC+Peak AC)
- DC accuracy: ±3%

6.2.4.1.1.1 DT5742 and DT5743

- Analogue Bandwidth: >0.5GHz
- Sample Rate: 5GSa/s (3.2GSa/s for DT5743)
- Bits:12
- ENOB: unlisted
- Number of Channels at full resolution:32+2 (16 for DT5743)
- Input Voltage: ± 1 V (±2.5V for V1743)
- Total Samples: 1024 per channel
- Notes: 200ns record length for DT5742, noise level 0.7mV RMS for DT5743
- Cost:

6.2.4.1.1.2 DT5761

- Analogue Bandwidth: 0.5GHz
- Sample Rate: 4GSa/s
- Bits:10
- ENOB: unlisted
- Number of Channels at full sample rate: 1
- Input Voltage:
- Total Samples:
- Notes:
- Cost:

6.2.4.2 Guzik SGA 6000 Series

- Bandwidth: 13GHz@1ch, 8GHz@2ch, 4GHz @4ch
- Bits: 8
- Vertical Scale (full): 2V
- Sample Rate: 40Gs/s for 1ch 20GSa/s for 2ch, 10GSa/s for 4ch
- Number of channels: 4
- Number of channels at full sample rate: 1

6.2.5 Low Profile Oscilloscopes and Digitizers

6.2.5.1 Keysight

6.2.5.1.1 DSO90008 Series Low-Profile High-Performance Oscilloscopes/Digitizers:

- Bandwidth: 8-13GHz
- Bits: 8
- Vertical Scale (full): 0.02V to 10V
- Sample Rate: 4GSa/s, 2GSa/s
- Number of channel: 2 @ 4GSa/s, 4 @ 2GSa/s
- Rack space: 1u
- SNR: 50 dB
- Noise: : 3% full scale or 4.5 mV, whichever is greater
- Maximum Input: 5 Vrms with 50 Ω input

6.2.5.1.2 DSO90008 DSO90808A Infiniium High-Performance Oscilloscope/Digitizer:

- Bandwidth: 8GHz – 13GHz
- Bits: 8
- Vertical Scale (full): 0.01V to 10V
- Sample Rate: 40GSa/s
- Number of channel: 8 @ 40GSa/s
- Rack space: 7u
- Noise floor: 2.8mV at 100mV/div (0.28% FS)
- SNR: 60 dB
- Price: $168k – $214k

6.2.5.2 Greenfield

6.2.5.2.1 GFT6012:

- Bandwidth: 3GHz
- Bits: 10
- Vertical Scale (full): 1V
- Sample Rate: 5GSa/s or 10GSa/s
- Number of channel: 2 @ 5GSa/s, 1 @10GSa/s
- Rack space: 1u
- SNR: 42dB

6.2.5.2.2 GFT6022:

- Bandwidth: 2.8GHz
- Bits: 12
- Vertical Scale (full): 1V
- Sample Rate: 1.8Gsa/s, @3.6Gsa/s
- Number of channel: 2 @ 1.8Gsa/s, 1 @3.6Gsa/s
- Rack space: 1u
- SNR: 58.5dB

6.3 Pre-Digitizer Input Modification (Additional Accessories & Options)

The purpose of this section is to introduce the concept of input protection and modification. The specific requirements for an individual application depend on the needs of that digitizer and the requirements of the system it is used in. Further development of technology in this field are required for the architecture presented in this paper to be successful.

6.3.1 Protection Clipper Circuits

The idea of an input protection clipper circuit is simple a passive element that senses an over voltage condition and provides a path to ground. In the case of fast transient signals like those experienced by diagnostics on NIF this circuit must react fast enough to protect in sensitive input of a high speed digitizer. The reaction time will be function of how the clipper circuit is designed. The clipper circuit may be as simple as a Shottky Barrier Diode or may be an active circuit with a sensing node, delay line, and RF transistors. The design of the clipper circuit should be subject of an additional systems engineering analysis to determine the proper requirements and architecture. For the purposes of this document it is assumed that such a protection circuit can be assembled to protect the input electronics of digitizers from expected overvoltage conditions. It is not necessarily expected that data could be recorded after the clipper circuit has activated.

6.3.2 High Speed RF Switches

Fast RF switches have existed for decades. By the use of delay lines and fast acting switches timed with the signal of interested input channels can be turned on and off to allow improved SNR at different points in the waveform. Gallium Nitride (GaN) transistors with switching times in the Sub-nanosecond timeframe are commercially available.

6.3.3 Log-Amps, Log-Attenuator, and Signal Compressors

Many of the signals observed in NIF are typically analyzed and displayed on logarithmic scales. Unfortunately most digitizers are set up to measure voltages in a linear manner. The concept of altering the input to record it in a logarithmic matter following a well-defined and repeatable manner is not unique to this field companies such as Pasternack make logarithmic amplifiers (FBLA-0.1/1-70BC 10MHz to 1GHz). Further analysis into the possible application of such a compressor is recommended.

7 Selection Analysis and Rational

7.1 Selection Criteria

The selection of a system architecture was performed in a top down manner evaluating each option using the key expectations. Once a general approach (Three option architecture with input accessories) was chosen it was compared to the current implementation. Then more specific possibilities with some research into existing hardware for the implementation of this were compared. The final Pugh Chart comparing specific hardware implementations reveals that further testing evaluation and flow down requirements are needed to derive a definitive conclusion.

7.2 Proposed Architecture Vs Current Pugh Chart

The current architecture consisting of obsolete Tektronix SCD5000 oscilloscopes, Greenfield FTD10000 oscilloscopes, and Tektronix 1GHz, 2.5GHz, 6GHz, and 12.5GHz, 7000 series and 70000 series oscilloscopes (versions A, B, and C with and without enhanced sample rate option) was compared to the proposed 3 option architecture described in the previous sections. The only category that the new architecture does not improve is performance. This is because the performance of the current digitizers was considered acceptable.

Key Expectation	Relative Weight (1-4)	Proposed 3 Option Architecture (w/Accessories)	Current Implementation (Tube and Digital
Performance	4	4	4
30 year Plan	2	4	1
Reliability	2	3	1
Rack space	3	4	1
maintenance and calibration needs	1	4	1
# Of Versions	1	3	1
Commercially Available	4	4	2
Totals (Higher is Better):	68 points possible	65	33

7.3 Option 1 High Precision and/or High Channel Count Pugh Chart

The decision to use a chassis based digitizer vs one of the other options (many scopes, stand-alone compact digitizers, low profile digitizers and the current implementation) shows that any alternative to the current implementation that utilizes the input accessories is an improvement. However, several options including stand-alone units and low profile digitizers cannot match the performance of the current implementation which is the first key acceptance criteria, making them unacceptable options.

Key Expectation	Relative Weight (1-4)	Chassis Based Digitizer (w/Accessories)	Many Digital Scopes (w/Accessories)	Stand Alone Compact Units (w/Accessories)	Low Profile Digitizers (w/Accessories)	Current Implementation (Tube and Digital)
Performance	4	4	4	2	1	4
30 year Plan	2	4	2	2	2	1
Reliability	2	3	4	3	3	1
Rack space	3	4	1	4	4	1
maintenance and calibration needs	1	4	4	4	4	1
# Of Versions	1	3	3	2	3	1
Commercially Available	4	4	4	4	4	2
Totals (Higher is Better):	68 points possible	65	54	52	49	33

7.4 Option 1 High Precision and/or High Channel Count Chassis based System Pugh Chart (down selecting implementation)

Within the chassis based digitizer options three major technology standards emerge, AXI/AXIe, PXI/PXIe, and VME. AXI is the newest standard, released 2009. Because it is fairly young few companies are developing hardware for this standard it does show the most promise in the future. VME is the oldest dating back to 1979 however there are limitations of the future potential and currently available options have slightly poorer performance than that offered by PXI and AXI. PXIe is shown to be the best option dating back to 1997 with many vendors building a variety of hardware modules for it. At this point in time PXI appears to be the "goldilocks" option, not too old and not too young. However, the difference between the three is not great enough to draw a final conclusion

Key Expectation	Relative Weight (1-4)	PXIe	AXIe	VME
Performance	4	4	4	3
30 year Plan	2	4	4	4
Reliability	2	3	3	3
Rack space	3	4	4	3
maintenance and calibration needs	1	4	4	4
# Of Versions	1	3	3	3
Commercially Available	4	4	3	4
Totals (Higher is Better):	68 points possible	65	61	58

7.5 OFD (Quality, Functional Deployment)

In an attempt to relate the key expectation to quantitative parameters a QFD matrix analysis matrix was developed. This is a high level QFD help develop testable performance metrics (TPMs) and guide the priority of requirements.

	Relative Weight (1-9)	Occupied Rack Space (how many U taken per channel)	Scalability (How many channels can be added)	How much new NIF Software is needed to be developed	Reliability (MTBF and MTTR)	Maintainability (how often is calibration required)	User interface (how easy is it to troubleshoot)	Vendor Supported Lifecycle (years produced and years suppored)	Cost Per Channel and ENOB (ENOB may reduce number of channels needed)	Effective Number of Bits (ENOB)	Record Length (ns of data recorded)	Sample Rate (Gsa/s)	Full Scale Range input voltage and adjustability	Vendor Supplied Software Functions (DSP, measurements, adjustment)	Bandwidth (GHz)	Vendor's Reputation (support, reliability, legacy)	Technology maturity (years and number of vendors involved)	Dynamic Range (single shot and shot to shot)	Signal to noise and Distortion (SNRD)
Performance	9	0	1	0	1	3	0	1	9	9	3	9	3	3	9	1	3	9	9
30 year Plan	3	9	9	1	9	9	1	9	3	0	0	0	0	0	0	3	3	0	0
Reliability	3	0	0	0	9	9	0	9	3	0	0	0	0	0	0	3	9	1	0
Rack space	7	9	9	0	1	0	9	0	3	0	0	0	0	0	9	0	3	1	1
maintenance and calibration needs	1	0	0	0	9	9	1	9	3	0	0	0	0	3	0	3	0	0	0
# Of Versions	1	3	3	9	9	9	1	9	1	1	0	1	1	3	9	0	0	0	0
Commercially Available	9	9	9	1	9	9	3	9	9	0	0	0	0	0	3	1	1	1	1
Weighted Total:		**174**	**183**	**21**	**169**	**180**	**95**	**162**	**205**	**82**	**27**	**82**	**28**	**33**	**180**	**39**	**93**	**100**	**97**
Highly Correlated Ranking		**3**			**4**	**2**		**5**	**1**						**2**				

Top characteristics related to the Key Expectations:

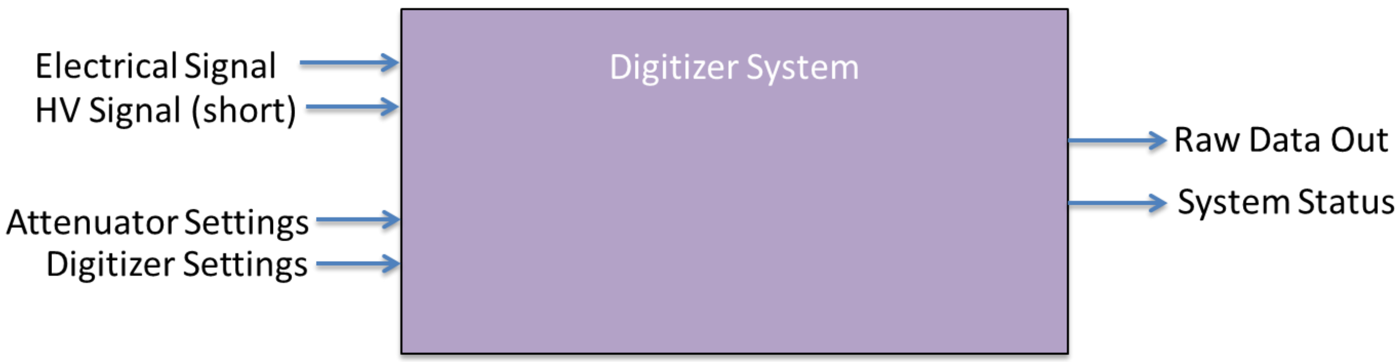
- Cost per Channel
- Maintainability (frequency of calibration)
- Bandwidth
- Rack Space
- Reliability (frequency of failures)
- Vendor Supported Lifecycle

Cost per channel is clearly the most important factor for all of the key expectations. Focusing on this metric throughout the design process may help provide engineering staff with insight into how likely they are to meet the key acceptance criteria. However, cost per channel is too general a metric and the way it relates to each expectation may conflict (one say spend more while another say spend less). Further analysis into how this is needed. Maintainability & Reliability scored high along with scalability. Mean time between failures and frequency of calibration are good candidates for testable performance metrics.

8 Proposed System Architectures

8.1 Simplified Top Level Functional Architecture

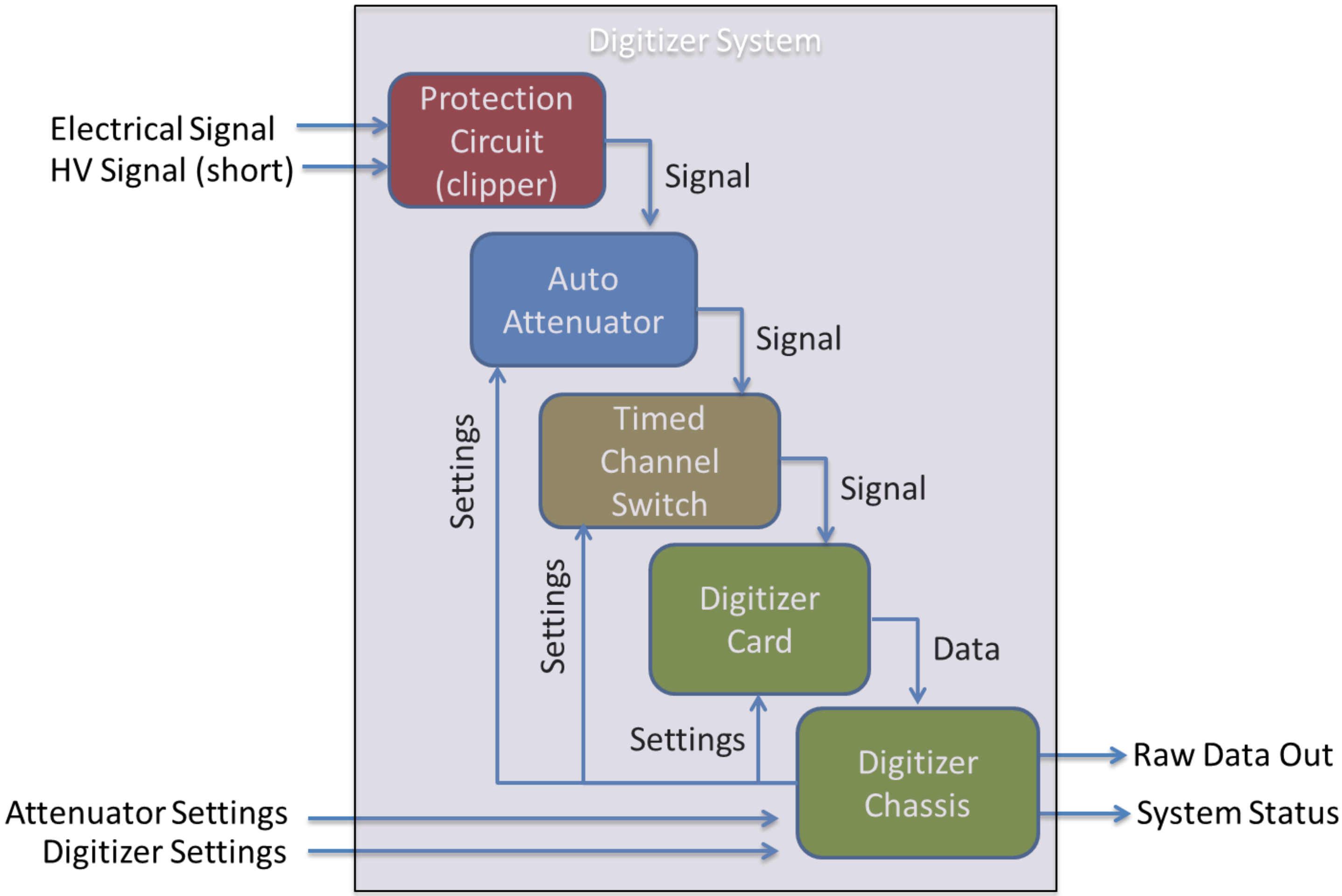
The top level functional architecture for this architecture is shown below. It is simply a black box that takes settings and signals in and processes them to produce raw data and outputs system status. For specific applications additional inputs and outputs may be necessary but all implementations must contain the minimum I/O shown below.



8.2 Simplified 1st Level Functional Architecture

The 1st level function architecture of the digitizer for option one is shown below. Options two and three have a potentially identical architecture with the exception of the chassis being removed. Depending on the application the protection circuit, auto attenuator, and channel switch may also be removed.

The primary input to the system is the electrical signal of interest. An input signal must first pass through a protection circuit that is designed to make sure only acceptable voltages are passed to the next elements in the system. This signal then passes through an automated attenuator element present if the specific system requirements have determined. The signal may than pass through a switch which again may or may not be present depending on the needs of the diagnostic this digitizer is working with. The signal is then digitized, the data passes through the chassis and out to the archive. The sub elements protection circuit, automated attenuator, switch may not be in the order shown depending on the exact system implementation. If option two or three is chosen then there will be no digitizer chassis. Setups setting are passed in to the system and system status is passed out.



9 *System Requirements*

Due to the fact that this analysis does not have a specific implementation only high level requirements flowing from the key expectations are listed. A new system engineering analysis for any new diagnostic must be performed which should leverage the information contained in this document. These requirements are only expected to serve as a starting place and should not be viewed as ridged or complete.

9.1 *High Level Requirements*

	Title	Requirement	Basis/Comment	Driving Key Expectation	Verification Method
1	Bandwidth	The bandwidth of the digitizer shall be twice that of lowest bandwidth component in the system.	Digitizer bandwidth requirements are based on the needs of the system	1	T
2	Sample Rate	The sample rate of the digitizer shall be at least 5 times greater than the	5x over sampling is generally accepted for transient waveforms	1	D

		minimum defined by Nyquist–Shannon sampling theorem based on the lowest bandwidth component of the system			
3	SNRD	The signal to noise and distortion (SNRD) of the system shall be defined by the total number of channels used to cover the input signal	For a digitizer system that utilizes multiple inputs with multiple attenuator and voltage scales the total SNRD from most sensitive to least sensitive shall be used to define system performance	1	T
4	ENOB	The effective number of bits of a digitizer channel shall be measured at the total system bandwidth frequency	ENOB for a system is defined by the system bandwidth not the maximum bandwidth of the digitizer	1	T
5	Protection Circuit	Digitizers shall have input protection circuits installed for any application where there is a potential for an overvoltage condition	This is to allow CRT based digitizers to be phased out	1	D
6	Maintenan ce	The digitizers system shall be able to be repaired or replaced in less than a 8 hour work period.	Any component or even the entire chassis can be removed and replaced quickly so the system can be returned to service.	2, 3, 5	I
7	Calibration	Digitizers shall not require routine calibration more than twice a year	Routine maintenance is defined as expected periodic calibration. Off-normal events that generated a need for calibration are not considered routine.	5	D
8	Form Factor	Digitizers with more than 4 channels and bandwidth less than 4GHz shall use a chassis/digitizer card architecture	This defines when an option 1 digitizer system is required	4,6	D
9	Chassis Standardiz ation	A single digitizer chassis standard shall be used for all current and future target diagnostic applications	This defines a single architecture for chassis based systems	2,6	D
10	Warranty	All components shall come	Extended warranties are	3,7	D

		with a minimum 1 year manufacturer's warranty	strongly recommended		
11	Availability	All components shall be commercially available in the United States	This requirement removes R&D/maintenance tasks out of the scope of Target Diagnostics as well as keeps hardware in line with what is being developed for other industrial applications	2,7	D
12	Safety	All components shall comply with all existing LLNL and NIF electrical safety standards	Standard boilerplate for all systems in NIF		I
13	Design Standards	All components shall comply with all existing LLNL and NIF design standards	Standard boilerplate for all systems in NIF		I
14	Bandwidth	The bandwidth of the digitizer shall be twice that of lowest bandwidth component in the system.	Digitizer bandwidth requirements are based on the needs of the system	1	T

Verification Method Definitions: Design, Test, Inspection, Analysis

10 Organizational Impact

There are significant long term impacts to the facility if the architecture laid out in this document is implemented. Over the life of the facility significant cost savings could be realized. Typically a backplane standard used in a digitizer chassis will be compatible with newer equipment for much longer than the individual component installed, meaning the chassis has a longer lifecycle. This means that a chassis will remain current and compatible as the individual components go out of date. As requirements change, individual cards fail, or newer versions become available replacements version can be installed without the need to replace the entire chassis this saves cost, time, and allows for future compatibility. Additionally the cost per GHz, ENOB, and channel has been on a continual downward trend for the last several decades (this is similar to what you seen in the personal computer industry). If this trend continues higher performance components will be available in the future for much less than they cost now. A system that can easily incorporate these is more likely to satisfy future requirements because of its flexibility and longer life cycle.

Reducing the consumed rack space will become a higher priority as more diagnostics are fielded. Systems required medium bandwidth will need to be as close to the Target Bay as possible. The diagnostic mezzanines were designed sever this purpose. These mezzanines cannot accommodate additional racks. These mezzanines are nearly full. Future systems will either need to occupy less space or an existing system will need to be removed. The architecture proposed will reduce consumed rack space for many future diagnostics and can potentially reduce rack space for many currently fielded diagnostics. Higher bandwidth systems that operate using an optical data transmission system do not need to be placed near the TB. If it's determined that systems bandwidth requirements are greater than 4GHz the equipment should be placed in a new diagnostic equipment location to help reserve mezzanine space for systems that are will benefit from being closer to their detectors.

By having three standard architectures engineers in the future will not need to spend as much time during the conceptual design phase addressing the digitizer. Control software for digitizers will not have to be rewritten for each new diagnostic. A standard architecture with fewer different models and components will reduce the total number of spares required. Currently each system is responsible for providing the maintenance origination with the appropriate number of spares for their equipment. New systems could leverage the existing pool of spares there for reducing the initial build cost and reducing the training required to replace equipment.

The impact of the benefits described in this section will not be felt immediately. To realize all the potential benefits this architecture must be applied consistently every year for the life of NIF with minimal exceptions. It is not appropriate to estimate a return on investment in a given number of years due to the fluctuation in diagnostics being fielded in any given year. However, follow on analysis based on the number, size, cost, and scope of future diagnostics in the next 5-10 years should produce a total dollar cost savings to the facility.

10.1 Summary of Benefits to NIF Target Diagnostics

- Cost savings:
  - Less labor required to setup a diagnostic
  - Less calibration costs
  - Less frequent failures
  - Reduce repair time (individual failed component replaced instead of entire
  - Individual digitizer cards cost less than entire scopes
  - A chassis has the potential to last and be compatible with currently available state of the art components for the life of the NIF project
- Racks Space
  - Digitizer chassis use less rack space per channel
  - Digitizer chassis have lower power and heat loads
  - Chassis can accommodate devices other than digitizers further reducing the need for additional external components installed elsewhere in the rack
  - Chassis
- Standardization
  - Reduced engineering development time for new systems
  - Reduced software development time for new systems
  - Reduced total number of spares because spares are compatible with multiple systems

11 Risk and Technology Assessment

11.1 Technology Assessment Parameters

As a follow up to this systems engineering analysis an integrated test plan to determine the best hardware implementation is required. The first step in this test plan should be to contact all possible vendors and ask them to provide the information listed in the bullets below. If they are unable or unwilling equipment should be borrowed, rented, or purchased. The equipment should then be tested. Once the test results are available they should be summarized along with the other information required in the table below. A weighted Pugh chart can then be generated that should make it clear vendor and models should be recommended.

- Digitizer Card and Chassis Parameters
  - Vendor Specified Bandwidth
  - ENOB @500MHz
  - ENOB @1GHz
  - Record length (total number of samples)
  - SNDR
  - Noise Floor
  - Time base stability
  - Channel to channel Jitter
  - Gain Accuracy
  - Overdrive Recovery Time
  - Overvoltage Input Damage threshold
  - Channel to Channel Crosstalk
  - Input voltage range and adjustment
  - Sample Rate
  - Input Impedance over bandwidth
  - Number of channels
  - Number of channels at a given sample rate (or maximum)
  - Rack space per channel
  - Maximum number of cards in chassis
  - Maximum number of channels in digitizer card
  - Calibration Requirements (frequency and equipment)
  - Cost per channel
  - Cost per ENOB
  - Product lifecycle duration (for sale and supported after)
  - Produce warranty and warranty extension options
  - Vendor reputation

- Oscilloscopes (for options two and three)
  - Vendor Specified Bandwidth
  - ENOB @expected operating bandwidth
  - Record length (total number of samples)
  - SNDR
  - Noise Floor
  - Time base stability
  - Channel to channel Jitter
  - Sample Rate
  - Gain Accuracy
  - Calibration Requirements (frequency and equipment)
  - Cost per channel
  - Cost per ENOB
  - Product lifecycle duration (for sale and supported after)

- Produce warranty and warranty extension options
- Vendor reputation

11.2 Research and Development Topics

As stated in section 6.3, research and development Pre-Digitizer input modification is needed to implement the architectures described in this document. At a minimum protection circuits are required to match the capabilities of CRT based digitizers.

- Protection Clipper Circuits
- High Speed RF Switches
- Log-Amps, Log-Attenuator, and Signal Compressors

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