# AIT/WATCHMAN DAQ Electronics Requirements

Document#.Revision# 2018001.1

## Change Log

| Revision | Description:Author | Date |
|---|---|---|
| 0 | Original document: D.Cowen (adapted from IceCube) | 21Feb2018 |
| 1 | Updated w/input from WG; added cross-WG dependencies | Apr-May2018 |
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# Using The Requirements Matrix

The RMD is structured around a Requirements Matrix that contains not only the requirements, but also the logic for how they were arrived at as well as the means by which confidence will be gained that the requirements have been met. Consolidating this information makes it very simple to perform both Validation and Verification tracking. Validation compares requirements against justification, Verification compares requirements against what was actually achieved.

## Requirement Number

For ease of reference, each individual requirement is assigned a unique number in the format of "X.YY". The first portion of this number indicates the general type of requirement:

| | | |
|---|---|---|
| 1. Functional | 4. Logistics | 7. Reliability |
| 2. Environmental | 5. Parts, Materials, Processes | 8. Growth |
| 3. Interface | 6. Quality | 9. Safety |

The second portion is a sequentially assigned numeral. In the event that requirements are subsequently added, the next available number is used. If requirements are deleted, the number is not reused.

## Requirement

This field contains the "official" project requirement statement for that particular item, and forms the basis for Validation and Verification activity. Upon approval and initial release of this document, the requirements as stated herein take precedence. (Any conflicts between these and statements in uncontrolled documents shall be resolved, and, if different, the ultimately selected statement placed here via change request.)

## Justification

This field contains two pieces of information that help establish a rational basis for the requirement and support any future change evaluation. The first is a short source summary indicating:

- **Allocated**- These are assigned at a higher system level, typically as a result of a budgeting or distribution decision.
- **Derived**- The requirement exists as a result of a design or implementation decision rather than being based on overall science needs.
- **Science Requirements**- These requirements trace directly from the overall instrument goals.

## Verification Method

Verification in this context means to assess confidence that the particular requirement has been met. There are a variety of methods available to accomplish this, including:

- **Analysis**- Mathematical or other defensible study of actual design performance versus requirement.
- **Demonstration**- The unit or system is operated in such a manner that substantial performance of the requirement can be logically inferred as a result.
- **Formal Test**- An engineering test, conducted per a defined test plan and with established pass/fail criteria.
- **Inspection**- Examination by visual or other means to asses whether the requirement has been met.
- **Simulation**- Probabilistic or other modeling representative of the system conditions indicates requirements will be met.

Methods are selected to give the needed confidence in the simplest and most direct manner possible, and can be revised with a higher or lower resulting risk impact.

## Verification Reference

Where external documentation exists (such as formal test plans, analysis, etc.) they will be indicated in this field.

**1. Functional**

| #.# | Requirement | Justification | Verification Method | Verif. Ref. | Comment(s); Input req'd from WG(s): |
|---|---|---|---|---|---|
| **1.01** | **Cold boot:** System must be able to boot up after extended shutdown with minimal manual intervention in less than several minutes. | Mine power reliability is unknown, and power outages can occur when no personnel are in lab. Require maximum uptime for supernova sensitivity. | **Controlled test** | | |
| **1.02** | **Single photon detection:** Each channel must be able to record single photoelectron (SPE) hits at a threshold of less than X mV. | SPEs are the fundamental datum for WATCHMAN and are essential for event reconstruction. | | | **PMT**: pulse height spectrum |
| **1.03** | **SPE time resolution:** The DAQ shall timestamp the leading edge of SPE hits with a resolution of less than 25% of the resolution due to the PMT TTS. | The downstream DAQ electronics should be a sub-dominant contributor to the overall timing resolution. Timing is critical for event reconstruction. | **Controlled test** | | **SAS:** Quantify degradation to reco due to time resolution. **PMT**: provide TTS |
| **1.04** | **Response linearity:** Each channel shall be able to record up to N SPE per second without degradation in gain. | Calibration devices, a galactic supernova and muon bundles can deposit large amounts of light in a channel. | **Controlled test** | | **SAS:** Impact of loss of linearity on reco quality. **PMT:** Impact of space charge? |
| **1.05** | **Per-Channel throughput:** Each channel shall be capable of processing PMT signals at an average rate of not less than X with zero deadtime. | Calibration devices, a galactic supernova, and cosmic-ray muons (0.1Hz at Boulby) will produce high event rates. | **Controlled test** | | **SAS, Calibration:** What is maximum event rate? |
| **1.06** | **Per-channel dead-** | Calibration devices, a | **Controlled** | | **SAS,** |

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| | **time:**<br>Each channel shall be capable of processing PMT signals at an average rate of not less than Y with X% deadtime. | galactic supernova, and cosmic-ray muons (0.1Hz at Boulby) will produce high event rates. | **test** | | **Calibration:**<br>What is maximum event rate? |
| **1.07** | **Trigger system throughput:**<br>The trigger system shall be capable of making trigger decisions at an average rate of not less than X with zero deadtime. | Calibration devices and galactic supernova will produce high event rates. | | | **SAS, Calibration:**<br>What is maximum event rate? |
| **1.08** | **Event throughput:**<br>The DAQ electronics shall be capable of forming and transmitting built events at an average rate of not less than X with zero deadtime. | Calibration devices and galactic supernova will produce high event rates. | | | |
| **1.09** | **Peak event throughput:**<br>The DAQ electronics shall be capable of forming and transmitting built events at a peak rate of not less than X with zero deadtime in a 100 second period. | Calibration devices and galactic supernova will produce high event rates. | | | |
| **1.10** | **Feature extraction:**<br>Each channel shall be capable of identifying and reducing SPE pulses to N bytes in size as, e.g., (q,t). | Bandwidth to central trigger board is limited. Requires pedestal subtraction to have been performed. | | | |
| **1.11** | **Data compression:**<br>Each channel shall | Bandwidth to downstream storage | | | |

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| | be capable of extracting the leading edge time and compressing complex (non-SPE) waveforms by a factor of X. | elements is limited. | | | |
| **1.12** | **Feature extraction/data compression disable:** Each channel shall be capable of disabling feature extraction and data compression for diagnostic purposes. | Full uncompressed waveforms are useful for debugging online algorithms and for evaluating in situ noise conditions. | | | |
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| **1.14** | **Absolute timestamping:** Each event shall be GPS-timestamped with a resolution not to exceed N microseconds. | Supernova neutrinos must be accurately timestamped for participation in global SN neutrino network and for triangulation | | | |
| **1.15** | **Extended pulse capture:** Each channel must be capable of recording data continuously for N ns | Muon events (0.1Hz at Boulby) will deposit large amounts of light that can reflect off detector surfaces multiple times before being detected. | | | **SAS:** What is the longest duration event? |
| **1.16** | **Dynamic range:** Each channel shall be capable of recording N photoelectrons in X ns. | Bright events should not saturate electronics channels. | | | |
| **1.17** | **Underground clock stability:** The underground clock for the underground electronics shall | Glitches and outages in the GPS signal will occur. The system needs to be resilient to these to maintain the integrity of its | | | **SAS:** What is required absolute timing stability for reactor, SN, SNEWS? |

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| | demonstrate a short-term stability of X over a period of 10 seconds and a long-term stability of Y over a period of 24 hrs. | absolute timing. | | | |
| **1.18** | **Double pulse resolution:** Each channel shall be capable of distinguishing as separate two photons arriving more than N ns apart. | Needed for accurate event reconstruction. (Correlated with 1.15: If capture extended pulse, can examine full waveform offline…) | | | **SAS:** What is double pulse resolution required by reconstruction? |
| **1.19** | **System linearity:** Each channel shall be capable of recording N p.e. in a 25ns (?) period. (Need similar requirement for longer period, e.g. 1µs?) | Needed for accurate event reconstruction. (Note: Muon bundles not much different from single muons–muons in bundle will arrive in detector simultaneously.) | | | |
| **1.20** | **Gain stability:** Each channel's gain must drift less than N% per week and less than M% per month. Specify dependence on temperature? | Needed for accurate event reconstruction. | | | **(**PMTs are driver for gain stability, so this is PMT WG responsibility. Electronics' contrib. likely small; use pulse injection to measure.) |
| **1.21** | **Inter-channel timing:** The system must be able to correlate individual channel timestamps to one another with less than 1ns precision. | Needed for accurate event reconstruction. Must verify full timing path. Burden on clock distribution system. | | | **SAS:** What inter-channel timing precision is needed for reconstruction? |
| **1.22** | **Digitizer crosstalk:** Interchannel digitizer crosstalk must be | Minimizes spurious hits. Needed for accurate event | | | **SAS:** What is PMT charge distribution? |

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| | less than N% of amplitude. | reconstruction. Look for signal that is large enough to trigger neighboring channel above some specified level. | | | How large are largest hits? |
| **1.23** | **Trigger threshold:** The system must be able to trigger on at least N channels in a $\Delta t$ ns window. | A low trigger threshold enables better understanding of trigger efficiency and the lowest possible neutrino energy threshold. | | | **SAS:** How low does trigger threshold need to be to understand trigger efficiency? |
| **1.24** | **Individual channel noise rate monitoring:** The system shall be capable of continuously monitoring the per-channel intrinsic noise rates and reporting these rates at regular intervals to the detector monitoring system. | Provides important measure of detector health and key input to detector simulation. | | | **PMT:** At what interval should PMT noise rate be monitored? |
| **1.25** | **Noise reduction:** The system shall be capable of applying digital signal processing (DSP) algorithms in real-time to individual channels to suppress external noise. | The *in situ* noise environment will not be known until the detector has been operated for some length of time. The ability to apply flexible DSP algorithms to the data increases the probability that such noise can be suppressed without deleterious impact on the actual signal. | | | |
| **1.26** | **End-to-end Tests:** The system must allow for end-to-end testing before being connected to all the | Debugged subsystems need to be tested together to ensure interfaces work. Internal calibration | | | |

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| | PMTs underground. | pulsers could mimic PMTs and help fully test the system in advance of connecting PMTs in situ.. | | | |
| **1.27** | **Full waveform data:** The system must be capable of transmitting full waveform data for channels having complex multi-p.e. signals on which the DAQ firmware cannot perform reliable pulse extraction. The deadtime incurred must be less than N ns after each full waveform digitization and transmission. | The firmware will be optimized to extract (q,t) from SPE signals. More complex MPE signals will require processing further downstream. | | | **SAS:** How often will PMTs see multiple p.e.'s and what deadtime can be tolerated to read them out as full waveforms? |
| **1.28** | **Channel buffer depth:** Each channel shall be capable of storing up to N ms worth of pulse-extracted data. | Buffering prevents data loss when downstream processing throughput is temporarily slower than usual. Assuming that 50ns windows define each signal, this translates to buffering about $10^6$ pulses per channel, or about 100s of data assuming a 10 kHz intrinsic noise rate per PMT. | | | **SAS, CAL:** What is the longest time period over which photons hit a single PMT for a burst of events or a particularly bright event (like a muon or a calibration source)? |
| **1.29** | **Trigger buffer depth:** The system shall be capable of buffering up to N seconds of trigger primitives from the full | Buffering prevents data loss when downstream data processing throughput is slower than usual. The 100s trigger buffer depth matches | | | **SAS, CAL:** What is the longest time period over which events might arrive at a rate |

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| | detector. | that of the per-channel buffer depth. One use case for a 100s buffer is a high-rate calibration source. Another is a galactic supernova. Each could deposit events in WATCHMAN over a period lasting about 100s. | | | significantly higher than data in normal running, e.g. from a calibration source or galactic supernova? |
| **1.30** | **Trigger bandwidth:** The trigger system shall be capable of handling a data bandwidth (input) of 0.7 GB/s. | The bandwidth is dominated by noise hits. Under the pessimistic assumption of an intrinsic PMT noise rate of 15 kHz, we estimate: 5600 PMTs * 15 kHz dark rate * 8 bytes per hit = 0.7 GB/s | | | **PMT:** Provide number of PMTs and PMT dark rate to enable DAQ WG to calculate trigger bandwidth |
| **1.31** | **Triggerless operation:** For reactor anti-nue data, the DAQ system shall be capable of forming its own trigger to initiate full detector readout for event building, i.e., it will not require an external trigger. | In normal operations, WATCHMAN's events will arrive at random times. | | | |

## 2. Environmental

| #.# | Requirement | Justification | Verification Method | Verification Reference | Comment(s); Input req'd from WG(s): |
|---|---|---|---|---|---|
| 2.1 | **Operating temperature:** The system shall be capable of operating in an ambient temperature ranging from 0-40C. | Temperature range dictated by ratings of individual electronic components. | | | **SITE:** Provide operating temperature of 0-40C for electronics. |
| 2.2 | **Transportation:** Electronic components, including printed circuit boards, connectors, power supplies… shall not be subject to mechanical or vibrational shock exceeding 10g(?), heat in excess of maximum rated storage temperatures of parts, or moisture during transport from point of assembly or testing to the mine. (Should we require accelerometers etc. inside shipment containers that are checked on arrival?) | Ensures no damage during shipment. Use standard parameters. | | | **LOGISTICS, PRO-CUREMENT:** Provide transportation of electronics minimizing mechanical shock and extreme temperatures. |
| 2.3 | ***In situ* humidity:** The electronics shall be capable of operating in an ambient humidity ranging from 40-60%. | A certain humidity level is required to minimize ESD. | | | **SITE:** Provide 40-60% humidity level for electronics. |
| 2.4 | **Electromagnetic compatibility:** EMC of the full system must be sufficiently low to induce a signal no larger than 50% of the single photoelectron threshold. | The system itself should not produce noise that creates spurious hits. | | | **SAS:** Confirm that noise at 50% of SPE threshold will not impact reconstruction. |
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## 3. Interface

| #.# | Requirement | Justification | Verification Method | Verification Reference | Comment(s); Input req'd from WG(s): |
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| **3.1** | **AC power:** The power supplies for the DAQ system shall provide a input voltage of 240 V, conditioned to have less than X% ripple. | Likely easier to get 240V in the UK than 120V, although this could present issues for initial system testing and debugging at US institutions. Mine power will likely be rather dirty and need conditioning for use by DAQ systems. | | | **SITE:** Provide mains power conditioning as specified by DAQ WG. |
| **3.2** | **Backup power:** The system shall have access to at least X minutes of uninterruptible power. | Hard, unplanned power shutdowns may damage PMTs, electronics and associated equipment. Robust UPS units enable controlled shutdowns. | | | **PMT:** Provide HV rampdown time to minimize possible damage to PMTs |
| **3.3** | **Average power consumption:** The system shall consume no more than 3 Watts per channel during continuous operation on average. | Lower power consumption can simplify the design, and lower the cost, of support components such as UPS units and cooling. | | | **SITE:** Provide this level of sustained power. |
| **3.4** | **Peak power consumption:** The system shall consume no more than 5 watts per channel during peak periods. | Initial boot-up and calibration sources may demand a high digitization and readout rate, resulting in higher than average power usage. | | | **SITE:** Provide this peak power level. |
| **3.5** | **GPS timestamp:** The system shall be provided with, | GPS timestamps are needed for accurate timestamping for | | | **SITE:** Provide GPS timestamp. |

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| | and be capable of applying, GPS timestamps. | event tagging, and for system debugging and calibration. | | | |
| **3.6** | **Data transmission:** The system shall be capable of transmitting built events with a bandwidth of X. | In normal operations, data should be continuously transferred to the surface. | | | **SITE, SAS:** Once SAS specifies trigger threshold, data bandwidth to surface can be estimated. |
| **3.7** | ***In situ* data storage:** The system shall be capable of storing up to one week's worth of data underground. | A failure of the data connection to the surface could require a long time to repair and should not result in lost data. | | | **DAQ S/W, SAS:** The in-situ storage for built events must be sufficiently large to store one week's data. Storage required depends on SAS-specified trigger threshold. |
| **3.8** | **Electronics racks:** The electronics shall fit in less than ~10 racks and the racks shall reside in close proximity to one another. | A more compact system is easier to power, cool, debug and maintain, and less expensive to provide with dedicated space underground. | | | **SITE:** Provide space for up to 10 racks of electronics in the mine. |
| **3.9** | **Electronics racks:** The racks containing electronics shall be electrically and mechanically connected to the floor of the room in which they are housed. | *Not sure about this one. Need input from safety officer for mechanical connection (don't want micro-quakes tipping over racks). Type of electrical connection requires input from electrical engineers.* | | | **SITE, SAFETY:** Provide mechanical and electrical connections of racks to floor/ground. |
| **3.10** | **Calibration source trigger:** The system shall provide input(s) for calibration systems to externally trigger | Enables full use of information provided by self-triggering calibration sources. Interface specification for trigger input will be | | | **CAL:** Information: External calibration triggers will be supported by DAQ. |

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| | readout of the detector and timestamp said trigger signal. | provided later. | | | |

## 4. Logistics

| #.# | Requirement | Justification | Verification Method | Verification Reference | Comment(s); Input req'd from WG(s): |
|---|---|---|---|---|---|
| **4.1** | **Identifiers:** Each PCB, crate and rack shall be clearly marked with a unique identifier–visually and, when possible, electronically– using a standard system to enable reliable tracking during testing, deployment, and long-term maintenance. | Standard practice. Long-term, will enable non-experts to assist with maintenance. | | | **LOGISTICS:** Provide a unique identifier system for various units in the DAQ system, like PCB cards, crates, racks, etc. |

**5. Parts, Materials, Processes**

| #.# | Requirement | Justification | Verification Method | Verification Reference | Comment(s); Input req'd from WG(s): |
|---|---|---|---|---|---|
| **5.1** | **Plating:** Cadmium, zinc and pure tin platings are prohibited. | *(Not sure about these items. Tin whiskers are a problem. Cadmium and zinc can introduce radioactivity.)* | | | **SITE, CLEANLINESS:** Comment on use of cadmium, zinc, tin in electronics. |
| **5.2** | **Parts derating:** Commercial electronic parts shall not be subject to operation in excess of 80% of their manufacturers' specifications. | Increases long term reliability. | | | **PROCUREMENT:** Provide commercial parts that will not operate in excess of 80% of manufacturer's spec. |
| **5.3** | **Preferred parts:** Parts selected for critical operating functions shall be chosen from manufacturers' "high reliability" designation... | *(This requirement needs discussion.)* | | | **PROCUREMENT:** Provide high-reliability parts. |
| **5.4** | **Parts lead time:** No part in the system shall have longer than a 6 month lead time. | Custom ASICs can have long lead times that can result in overall project delays. | | | **PROCUREMENT:** Do not select parts with overlong procurement lead times. |
| **5.5** | **Cost:** The cost per channel, including parts and new engineering effort, shall not exceed that of a fully commercial solution. | (Should this be considered a requirement? Not sure.) | | | **PROCUREMENT:** Do not exceed per-channel cost of a fully commercial DAQ solution (e.g., from CAEN) |

**6. Quality**

| #.# | Requirement | Justification | Verification Method | Verification Reference | Comment(s); Input req'd from WG(s): |
|---|---|---|---|---|---|
| **6.1** | **Supplier selection:** Whenever possible, parts used in the electronics shall be selected from manufacturers in the DoD Qualified Manufacturer List (QML) and NASA's Active Parts Core Suppliers List (CSL). | Repairs of electronics will be made more difficult by the deep underground location. Choosing more reliable parts decreases the number of such repairs that will be needed. | | | **PROCUREMENT:** Provide parts from suppliers meeting high standards. |

## 7. Reliability

| #.# | Requirement | Justification | Verification Method | Verification Reference | Comment(s); Input req'd from WG(s): |
|---|---|---|---|---|---|
| 7.1 | **Inherent reliability:** Individual electronics channel failure rate shall not exceed X% over a 3 yr period. The number of hot-spare DAQ and HV(?) boards shall be 2X%. | Underground debugging and repair is difficult and should be minimized. | | | **PROCUREMENT:** Provide sufficient spares to enable construction of double the number of channels predicted to fail. |
| 7.2 | **Hot-spare Storage:** There shall be storage available for hot spare DAQ crates, cards and HV supplies. | A likely mode of operation will be to store hot-spares in the mine and use them to replace faulty items, which will be brought to the surface for repair. | | | **SITE:** Provide underground storage for hot spares |
| 7.3 | **Built in test and diagnostics:** The system shall be capable of self-testing all important aspects of its operation, including individual channel data acquisition, pulse extraction and triggering. | Enables remote debugging and repair support. Regular use demonstrates system operationality. | | | |
| 7.4 | **Built in temperature sensor:** Each PCB and other key components shall be capable of monitoring and reporting their ambient temperatures over a range of -10–100C | Important for maintaining and monitoring DAQ hardware health. | | | |

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| | with accuracy of ±2.5C and at 12 bit resolution. | | | | |
| **7.5** | **Failure propagation:** The failure of a single PMT or card or group of same shall not result in failure or degraded operation of other PMTs or cards or other groups of same. | DAQ must be able to continue acquiring quality data even if one or more PMTs or cards fail, or groups of same have failed. | | | |
| **7.6** | **Long term maintenance:** Senior personnel at the institution(s) designing and procuring key elements of the DAQ hardware must make a long-term (5yr?) commitment to support the maintenance of those elements. | It is already hard to maintain institutional memory, but transferring knowledge of complex, custom-built systems across institutions is nearly impossible. | | | |
| **7.7** | **Surface repair facility:** An electronics testing and debugging facility shall be made available in or near the Boulby Lab surface building, with space, cooling and power for one rack, a ESD-safe workbench with space for an oscilloscope, other test equipment, a soldering station,… | While some debugging and repairs can be done underground, it will be much more efficient to do so above ground whenever possible. | | | **SITE:** Provide an electronics repair facility on the surface. |

## 8. Growth

| #.# | Requirement | Justification | Verification Method | Verification Reference | Comment(s); Input req'd from WG(s): |
|---|---|---|---|---|---|
| **8.1** | **Future photosensors:** The system shall be scalable and in particular shall support the timing resolution and other operational requirements of future photosensor tests performed alongside existing channels. | AIT/WATCHMAN is tasked with providing a testbed for future technologies. These technologies will need to be verified against the detector's well-understood photosensors.<br><br>Examples:<br>1. LAPPDs will require ~100ps timing resolution.<br>2. Small 3" PMTs may require sophisticated real-time local coincidences. | | | |