EX1401

16-CHANNEL ISOLATED THERMOCOUPLE/VOLTS INSTRUMENT

USER'S MANUAL

P/N: 82-0156-000
Feb 28th, 2017

VTI Instruments Corp.
2031 Main Street
Irvine, CA 92614-6509
(949) 955-1894

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CERTIFICATION

VTI Instruments Corp. (VTI) certifies that this product met its published specifications at the time of shipment from the factory. VTI further certifies that its calibration measurements are traceable to the United States National Institute of Standards and Technology (formerly National Bureau of Standards), to the extent allowed by that organization's calibration facility, and to the calibration facilities of other International Standards Organization members.

WARRANTY

The product referred to herein is warranted against defects in material and workmanship for a period of one year from the receipt date of the product at customer's facility. The sole and exclusive remedy for breach of any warranty concerning these goods shall be repair or replacement of defective parts, or a refund of the purchase price, to be determined at the option of VTI.

For warranty service or repair, this product must be returned to a VTI Instruments authorized service center. The product shall be shipped prepaid to VTI and VTI shall prepay all returns of the product to the buyer. However, the buyer shall pay all shipping charges, duties, and taxes for products returned to VTI from another country.

VTI warrants that its software and firmware designated by VTI for use with a product will execute its programming when properly installed on that product. VTI does not however warrant that the operation of the product, or software, or firmware will be uninterrupted or error free.

LIMITATION OF WARRANTY

The warranty shall not apply to defects resulting from improper or inadequate maintenance by the buyer, buyer-supplied products or interfacing, unauthorized modification or misuse, operation outside the environmental specifications for the product, or improper site preparation or maintenance.

VTI Instruments Corp. shall not be liable for injury to property other than the goods themselves. Other than the limited warranty stated above, VTI Instruments Corp. makes no other warranties, express or implied, with respect to the quality of product beyond the description of the goods on the face of the contract. VTI specifically disclaims the implied warranties of merchantability and fitness for a particular purpose.

RESTRICTED RIGHTS LEGEND

Use, duplication, or disclosure by the Government is subject to restrictions as set forth in subdivision (b)(3)(ii) of the Rights in Technical Data and Computer Software clause in DFARS 252.227-7013.

VTI Instruments Corp.
2031 Main Street
Irvine, CA 92614-6509 U.S.A.

DECLARATION OF CONFORMITY

Declaration of Conformity According to ISO/IEC Guide 22 and EN 45014

MANUFACTURER'S NAME	VTI Instruments Corp.
MANUFACTURER'S ADDRESS	2031 Main Street Irvine, California 92614-6509
PRODUCT NAME	Precision Voltage/Temperature Measurement Instrument
MODEL NUMBER(S)	EX1401
PRODUCT OPTIONS	All
PRODUCT CONFIGURATIONS	All

VTI Instruments Corp. declares that the aforementioned product conforms to the requirements of the Low Voltage Directive 73/23/EEC *and the* EMC Directive 89/366/EEC *(inclusive* 93/68/EEC*) and carries the "CE" mark accordingly. The product has been designed and manufactured according to the following specifications:*

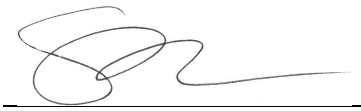
SAFETY	EN 61010-1:2010 (3rd Edition)
EMC	European Standards CISPR 11 EN 61000-3-2, EN 61000-3-3 EN 61326-1 (which is a product family of EMC standards which references EN 61000-4-2, EN 61000-4-3, EN 61000-4-4, EN 61000-4-5, EN 61000-4-6, EN 61000-4-8, and EN 61000-4-11)
SHOCK AND VIBRATION	MIL-PRF-28800F, Paragraphs 4.5.5.3.1, 4.5.5.3.2, & 4.5.5.4.1 (Unit operated without error during test process)

This product was tested in a typical configuration.

I hereby declare that the aforementioned product has been designed to be in compliance with the relevant sections of the specifications listed above as well as complying with all essential requirements of the Low Voltage Directive.

February 2017

CE



Steve Mauga, QA Manager

GENERAL SAFETY INSTRUCTIONS

Review the following safety precautions to avoid bodily injury and/or damage to the product. These precautions must be observed during all phases of operation or service of this product. Failure to comply with these precautions, or with specific warnings elsewhere in this manual, violates safety standards of design, manufacture, and intended use of the product. Note that this product contains no user serviceable parts or spare parts.

Service should only be performed by qualified personnel. Disconnect all power before servicing.

TERMS AND SYMBOLS

These terms may appear in this manual:

WARNING Indicates that a procedure or condition may cause bodily injury or death.

CAUTION Indicates that a procedure or condition could possibly cause damage to equipment or loss of data.

These symbols may appear on the product:

Attention and Warning - Important safety instructions, refer to manual

Warning, possibility of electric shock, refer to manual

Frame or chassis ground

Safety ground, required to be connected to local earth ground

Indicates that the product was manufactured after August 13, 2005. This mark is placed in accordance with *EN 50419, Marking of electrical and electronic equipment in accordance with Article 11(2) of Directive 2002/96/EC (WEEE)*. End-of-life product can be returned to VTI by obtaining an RMA number. Fees for take-back and recycling will apply if not prohibited by national law.

WARNINGS

Follow these precautions to avoid injury or damage to the product:

Apply local earth ground The safety earth ground cable provided with this instrument meets the required regulatory and statutory safety standards as indicated by this product's declaration of conformity. The green/yellow safety cable must be applied between the safety ground on the rear of the unit and the local safety earth ground. This is required for safe operation of the equipment. Refer to the manual on how to apply the safety earth ground cable.

Use Proper PoE+ Source

This unit can be powered over Ethernet via PoE+ (IEEE 802.3at). When using PoE+ to power your unit, only use VTI recommended powered Ethernet switches, a list is available in this manual. Using a powered switch that is not on VTI's recommended list may not work.

Use Proper AUX Source

This unit can be optionally powered with an external DC source. When using the AUX DC Input to power your unit, VTI recommends using external supply (VTI# 56-0739-000). If desired, a different DC supply can be used if it meets the voltage, power, connector, and safety requirements. Use a power source that meets the same safety and CE requirements listed on the declaration of conformity for this product. Verify that the connector pin-out is the same as required for this product.

Avoid Electric Shock

To avoid electric shock or fire hazard, do not operate this product with the covers removed. Do not connect or disconnect any cable, probes, test leads, etc. while they are connected to a voltage source. Remove all power and unplug unit before performing any service. ***Service should only be performed by qualified personnel.***

Operating Conditions

To avoid injury, electric shock or fire hazard:

- Do not operate in wet or damp conditions.
- Do not operate in an explosive atmosphere.
- Operate or store only in specified temperature range.
- Provide proper clearance for product ventilation to prevent overheating.
- DO NOT operate if any damage to this product is suspected. Product should be inspected or serviced only by qualified personnel

Improper Use

The operator of this instrument is advised that if the equipment is used in a manner not specified in this manual, the protection provided by the equipment may be impaired.
Conformity is checked by inspection.

SUPPORT RESOURCES

Support resources for this product are available on the Internet and at VTI Instruments customer support centers.

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SECTION 1

INTRODUCTION

OVERVIEW

The EX1401 provides a total of 16 isolated channels for precision voltage and temperature measurement. Its combination of measurement performance and integrity, configuration flexibility, package density, and network connectivity make it the most powerful, yet easy-to-use, instrument of its kind. The EX1401 is a complete, self-contained temperature measurement system that communicates over Ethernet and can be optionally powered over the same Ethernet cable. Unlike other data acquisition offerings in its class, the EX1401 offers a tightly integrated solution that frees the user from the complexity of marrying terminal blocks, signal conditioning cards, digitizer, power supply, and chassis together.

The EX1401 also provides a level of measurement integrity and channel independence that far exceeds the typical data acquisition system. Absent are caveats about scanning speed, channel order, and overload effects. In the EX1401, channels have no influence on each other, regardless of scanning speed or channel state. Excellent common mode rejection performance provides immunity from not only power line interference, but also high frequency noise. Moreover, it aids in maintaining overall system integrity by offering a high-performance open transducer detection system. The EX1401 provides isolation from earth and channel to channel. This provides worry free measurements in high voltage environments like automotive and battery test.

The EX1401 provides a high level of configuration flexibility as well. Each channel can be configured independently with regards to measurement function, filter setting, and limit values. In addition to measuring all standard thermocouples, the EX1401 can be programmed with user-defined thermocouple polynomial equations or be used as a low-noise voltmeter. Scanning speed is programmable up to a maximum of 20 kSa/s (kilosamples per second), independent of the number of channels being scanned. This combination of filtering and scanning speed provides the EX1401 with the low noise performance required for sensitive applications as well as the speed necessary to measure fast, fine-gauge thermocouples.

For highest accuracy and stability, the EX1401 provides a precision analog temperature sensor, per channel, to measure the cold-junction of the mini TC connector. The accuracy of this reference junction temperature sensor is typically within +/- 0.05C (20C to 30C operating temp.) Thermocouple accuracy is detailed in Table 1.

The EX1401 is as easy-to-use as it is powerful. An integrated web page provides a convenient way to instantly verify communications and instrument functionality, while industry standard IVI drivers provide a familiar application programming interface to reduce integration and program development time.

FEATURES

Combined Thermocouple and Analog Inputs

Easily combine thermocouple and analog signals on these versatile instruments with sampling rates up to 20 kSa/s per channel. Each input incorporates an independent signal conditioning path with

software selectable filters for maximum flexibility. Complete channel independence ensures data integrity regardless of sample speed or input overload conditions.

Scalable for Synchronized High-Speed, High-Channel Count

In addition to base class LXI compliance, this instrument also provides extended capabilities like LXI Clock Synchronization, LXI Event Messaging, and LXI Time Stamped Data, to support easy integration and synchronization of multiple devices, including existing VXI / PXI / PXIe bus instrumentation.

Open Thermocouple Detection (OTD)

While the integration of the EX1401 removes many of the reliability and connectivity problems typically faced by system designers, they still must contend with the reliability of the sensor connections. Fortunately, the EX1401 aids a great deal in that regard as well. Each thermocouple input channel generates a very small current (5 nA/channel) which drives the input to an open-circuit state if the transducer is disconnected. Implemented in this way, open transducer detection is continuous and requires no discrete function call on the part of the user to be activated, offering more protection than systems that only check on command, as a broken sensor can occur at any time during testing, not just at installation. In a typical application, the OTD has no effect on the measurement.

NOTE Many thermocouple simulators have a much higher impedance than a thermocouple so an offset may be introduced into the reading when using a simulator. In general, the OTD should only be active on channels that are being used with actual thermocouples.

The EX1401 additionally offers a front panel OTD LED for each channel that illuminates upon the recognition of a fault condition. This provides for quick and easy problem channel identification. Moreover, to ensure that even intermittent problems are identified, the fault recognition is a latching mechanism, retaining the information of the current acquisition sequence until a new acquisition is initiated.

Cold Junction Compensation (CJC)

For highest accuracy and stability, the EX1401 provides a precision, analog temperature sensor, per channel, to measure the reference/cold-junction of the mini TC connector. CJC channels are measured with a separate, dedicated ADC, per channel and are time correlated to the thermocouple channel. For those users that prefer to employ an external cold junction, the EX1401 also allows for the programming input of up to sixteen unique external cold junction temperatures, one for every input channel. Moreover, the use of internal and external CJC inputs can be mixed throughout the unit on a per channel basis. As the CJC sensors are placed in an isothermal environment, they are not disturbed by instrument air cooling fan, as well as thermal disturbances from adjacent channels.

Triggering

The EX1401 supports a full function trigger model with a separate arm source and trigger source event structure. Trigger and arm source events can be independently programmed from a variety of sources including Immediate, Software, External TTL, Digital I/O, LAN events, and LXI alarms.

Simplified Installation, Setup and Control

In addition to compliance to LXI base specifications, the EX1401 also implemented the LXI Clock Synchronization, and LXI Event Messaging, Time Stamps and Event Logs. These features make the EX1401 instruments ideal for distributed measurements throughout a facility – reducing cabling and installation expense. The ability to connect directly to an Ethernet network using industry standard Ethernet cable and connections makes it easy for network administrators to oversee the installation. Using a PoE+ enabled Ethernet switch allows both power and measurement data on a single wire. Experience how *IVI Digitizer class* driver compliance simplifies installation and setup.

An onboard, web-accessible user interface allows you to instantly verify communications and instrument functionality, while IVI drivers provide a familiar application programming interface to further reduce integration and program development time. For comprehensive, programming-free data recording setup, management and viewing, use EX1401 instruments with one of VTI's full-featured, turnkey software solutions, such as EXLab.

Channel Independence

Each of the EX1401's 16 differential input channels is an independent signal conditioning path, complete with amplification and continuous open transducer detection. This independence frees the user from the problem of channel-to-channel crosstalk that is pervasive in most multi-channel data acquisition systems. In the EX1401, channels have no influence on each other, regardless of scanning speed or channel state. Specifically, open or significantly overloaded channels do not affect the measurement results of any other channels.

Custom Thermocouple support

When configured in thermocouple mode, each input can be individually configured to support specific type of thermocouple. In addition to supporting standard thermocouple types (J, K, T, E, S, R, B and N), the EX1401 can also support custom thermocouple types (for example: C-Type), through the input of user-defined thermocouple polynomial coefficients. Each of the EX1401's channels can be configured with a unique custom 12^{th} order polynomial for both voltage-to-temperature and temperature-to-voltage conversions.

Analog Filter

Each EX1401 input channel has a fixed, 2-pole, 30kHz low pass filter with an RC response providing anti-alias filtering. The analog signals after the anti-alias filter are over sampled at 320kHz to 640kHz by the ADCs. This combination of anti-alias filter with ADC oversampling provides 60dB of rejection at the aliasing band.

Digital Filter

The EX1401 allows the user to configure different types of digital filters per channel. These digital filters are implemented inside the FPGA of the device, such that they perform consistently and without loading the host computer resources. Users can optimize the filter settings for aggressive filter performance or lower data latency time. In addition, users can customize the FIR filter performance by editing the coefficients of the filter. This provides ultimate flexibility in designing a filter to suit the application needs.

Input Connectors

The EX1401 employs uncompensated (Cu-Cu) mini-thermocouple female jacks as an input connector. This connector provides a solid, reliable connection that is also easily changeable. Since it is not thermocouple-type specific, different thermocouple types can be mixed throughout the unit without hardware modification.

Sampling Rate

The EX1401 is designed for sampling speeds up to a 20 kSa/s per channel, regardless of the number of enabled channels. However, it is possible to achieve varying sampling rates from less than 1Sa/sec per channel, to 20kSa/sec per channel, using various data decimation filter settings. When the requested sampling rate is less than 10 kSa/s, the EX1401 automatically filters and decimates the data to achieve the down sampling rate. This offers improved noise performance and band limitation, while maintaining the requested data output rate.

Digital I/O and Limits

The EX1401 allows the users to define a unique set of programmable limits that are used for open transducer detection as well as general purpose input channel monitoring. These limits are programmable on a per channel basis and are evaluated, within the instrument with each completed scan. The output of limit evaluations is presented via front panel LEDs, digital I/O port, and through the instrument driver.

The EX1401 features an 8-channel digital I/O port on the rear panel of the instrument. This port can be used as an arm/trigger source, for presentation of limit evaluation information, and as a general purpose output device. As a general purpose output device, each DIO channel can be independently programmed with regards to its output functionality and its static level to assume when enabled as an output. For expanded and more automated operation, each DIO channel can be independently linked to one or multiple limit conditions on one or more input channels.

Triggering

The EX1401 supports a full function trigger model with a separate arm source and trigger source event structure. Trigger and arm source events can be independently programmed from a variety of sources including Immediate, Software, External TTL, Digital I/O, LAN events, and LXI alarms.

Multi-Function Display

The menu driven LCD display available on the rear side of the instrument provides instrument status, diagnostic reports, network details, and can also start, stop, and monitor measurement sequences that log data to an external USB disk without PC control.

USB Data Recording

The EX1401 can export acquisition data at full speed to an external USB memory device, so that it can be used as a standalone data logger. This will also be useful to keep a redundant back up of data for high reliability applications, while streaming data over the Ethernet interface. It supports standard maximum partition size of all of EXT2, EXT3, EXT4, VFAT/FAT32, and MSDOSFS filesystems. The data will be stored in Hierarchical Data Format, HDF5 file format. HDF5 being an open standard data file format, users can choose from a wide variety of tools to decompress, view and export the time stamped measurement data. For more information on HDF5 file formats and tools, visit the HDF Group's website: https://www.hdfgroup.org

End-to-End self-test

The EX1401 can perform internal diagnostics through self-test mechanism. This Built-In-Self-Test (BIST) checks for internal board voltage levels, system temperature, various status indicators, LEDs, cooling fan, LCD display and +2.5V reference voltage on every input channel, and health of internal CJC sensors. This self-test will be performed automatically upon power-up, and can be initiated though software or the rear panel LCD interface, any time after the instrument is booted. This Built-In-Self-Test provides test system confidence and peace of mind by ensuring that the complete instrumentation measurement path is functional and delivers the most accurate result possible.

EX1401 SPECIFICATIONS

GENERAL SPECIFICATIONS	
NUMBER OF CHANNELS	
EX1401	16 electrically isolated and fully differential inputs
INPUT POWER	
Input voltage	10V to 50V DC
Power (AUX)	12 W typical
PoE+ Power	12 W typical
CHANNEL TYPES	
Input channel type	Thermocouple or Voltage (software selectable, per channel)
MEASUREMENT SAMPLING RATE	
	Minimum: 1 Sample every 5 days, per channel Maximum: 20,000 Samples per Second, per channel
MEASUREMENT RESOLUTION	
	24 bit
TEMPERATURE ACCURACY	
	See Table 1 **Error! Not a valid bookmark self-reference.**
TEMPERATURE RESOLUTION	
	< 0.001 C
PROGRAMMABLE DIGITAL FILTERS	
None (No Filter)	Raw data
High Performance (FIR)	1 to 16 number of /2 stages (Selectable & Customizable)
Low Latency (CIC)	/4 to /8192 (Selectable)
Medium Latency (CIC+CFIR)	Low latency CIC filter, followed by /4 FIR Filter (Customizable)
Post Filter Blind Divider	1 - 65536 (selectable)
VOLTAGE INPUT RANGE	
Voltage input mode	±0.01 V, ±0.10 V, ±1.0 V, ±10.0 V
Thermocouple input mode	±0.10 V for temperature measurement
INPUT OVERVOLTAGE PROTECTION	
	Up to ±100V peak between the two inputs of the mini TC connector
INPUT COUPLING	
	DC only
VOLTAGE RESOLUTION	
±10.0 V	1.7 uV
±1.0 V	150 nV
±0.1 V	13.5 nV
±0.01 V	1.7 nV
VOLTAGE ACCURACY	**± (% of reading + offset)**
±10.0 V	±(0.025% + 500uV)
±1.0 V	±(0.025% + 50uV)
±0.1 V	±(0.025% + 10uV)
±0.01 V	±(0.05% + 10uV)
VOLTAGE OFFSET STABILITY	
±10.0 V	± 20 µV/°C typical
±1.0 V	± 10 µV/°C typical
±0.1 V	± 5 µV/°C typical
±0.01 V	± 2 µV/°C typical
VOLTAGE GAIN STABILITY	
Voltage input channels (all ranges) and thermocouple input channels	± 25 ppm/°C
INPUT IMPEDANCE	
	20 MΩ differential (DC input) 1.7 MΩ differential (60 Hz input) 180 kΩ differential (1000 Hz input)
INPUT DC BIAS CURRENT	
	5 nA typical
ISOLATION - ANALOG	

GENERAL SPECIFICATIONS

Input channel to Ground	±500 V Peak continuous working voltage
Input channel to channel	±1000 V Peak continuous working voltage between channels
Impedance across barrier	100pF || Gas Discharge Tube rated for 600V

COMMON MODE REJECTION RATIO (CMRR), TYPICAL

	DC	50/60 Hz	400 Hz	1000 Hz
10mV range	-130 dB	-130 dB	-130 dB	-120 dB
100mV range	-130 dB	-130 dB	-130 dB	-120 dB
1V range	-130 dB	-130 dB	-130 dB	-120 dB
10V range	-130 dB	-130 dB	-130 dB	-120 dB

The 10V input range will be reduced by increasing common mode AC voltage above 100Vpk/60Hz.

CHANNEL TO CHANNEL CROSSTALK, TYPICAL

-140 dB <1kHz

TOTAL HARMONIC DISTORTION (THD), TYPICAL

	100 Hz full scale input	1 kHz full scale input
100mV range	-85 dB	-75 dB
1V range	-87 dB	-77 dB
10V range	-90 dB	-80 dB

NOISE, TYPICAL, IN MICROVOLTS (PEAK TO PEAK)

Sample Rate (SPS)	10V	1V	100mV	10mV	Temperature
10,000	966	65	16.2	13.6	0.34 C pp
1,250	350	24	5.7	4.7	0.11 C pp
156.25	119	9	2.0	1.6	0.04 C pp
19.53	46	4	0.8	0.6	0.02 C pp

PASSBAND RIPPLE

<±0.005 dB over the passband of 0.45 * Sample Rate

NETWORK CONNECTION

10/100 Base-T (auto MDI-X)

INPUT CONNECTORS

Cu-Cu mini-TC jack (Thin spade plug polarity is positive)

OPERATING TEMPERATURE

0 °C to 50 °C

DIMENSIONS

1.68” H x 8.69” W x 10.00” D (all dimensions are in inches)

RELIABILITY

MTBF	> 225,000 hours
Methodology	Telcordia (Bellcore) SR-332, Issue 3 Environment = GB, Quality Level = II, 25C ambient environment, 90% UCL

CLK AND TRG SPECIFICATIONS

ELECTRICAL SPECIFICATIONS

Maximum Input Voltage	-0.5V to 5.5V, ESD protected
Input Impedance	50 Ohm series terminated with a 10k Ohm pulldown resistor
Minimum Input Pulse Width	1 µs
Maximum Output Frequency (CLK)	10 MHz
V_{IL}	< 0.8V
V_{IH}	> 3.5V
V_{OL}	< 0.65V @ 32 mA
V_{OH}	> 3.0 V @ 32 mA
I_{MAX}	50mA max

INPUT CONNECTORS

SMB

DIO Specifications

Number of DIO channels	
	8
Electrical Specifications	
Maximum Input Voltage	-0.5V to 5.5V, ESD protected
Input Impedance	Signal is pulled low by a 10k Ohm resistor
Minimum Input Pulse Width	100 µs
Minimum Output Pulse Width	100 us, updated synchronously with the ADC sampling, prior to decimation
V_{IL}	< 0.8V
V_{IH}	> 2.0V
V_{OL}	< 0.55V @ 10 mA
V_{OH}	> 2.0 V @ 10 mA
I_{MAX}	10mA max per channel, 20mA max per bank
Isolation - Digital	
Input channel to Ground	±250 V Peak continuous working voltage
Input channel to channel	N/A (bank isolated)
Impedance across barrier	1000pF ‖ 10MΩ ‖ Gas Discharge Tube rated for 600V
Connector	
	9 pin standard D-Sub Female socket

LXI Specifications

LXI Class Compliance (v1.4)	
	LXI Core + Clock Synchronization + Event Messaging + Event Logs + Time Stamped Data + IPv6 Support
Clock Specifications	
Clock oscillator accuracy	±20 ppm (when free running as Master, with no other clocks)
Synchronization accuracy	Reports "synchronized" when < ±300 ns of the 1588 master clock
Default 1588 Sync threshold	Configurable (default is 300 ns)
Timestamp	
Accuracy	As good as time synchronization down to 40 ns
Resolution	40 ns
IEEE 1588-based Trigger Timing	
Alarm	
Trigger time accuracy	As good as time synchronization down to 40 ns
Time to trigger delay	40 ns
Receive LAN[0-7] Event	
Trigger time accuracy	As good as time synchronization down to 40 ns
Time to trigger delay	
Future timestamp	40 ns typical
Past/zero timestamp	Unspecified (Based on processor workload)
Hardware Trigger Timing	
DIO IN time to trigger delay	Min: 50 ns Max: 100 ns
EXT TRIG in to timestamp delay	Min: 46 ns Max: 86 ns
Internal event / state to EXT TRIG OUT time delay	Min: 40ns Max: 80ns
Internal event / state to DIO OUT time delay	Min: 50 ns Max: 100 ns
LAN event in with event time !=0	0 to 40ns (because of clock granularity)
LAN event in with event time == 0	(unspecified)
LAN event Out timestamp granularity	40ns

ENVIRONMENTAL SPECIFICATIONS FOR EX1401	
OPERATING LOCATION	
	This module should be operated indoors in a controlled environment, protected from exposure to the elements (i.e. direct sunlight, precipitation, wind, etc.).
TEMPERATURE	
Operating	0 °C to +50 °C
Storage	-40 °C to +70 °C (MIL-PRF-28800 Class 3)
HUMIDITY	
	5% – 95% (non-condensing) (MIL-PRF-28800 Class 3)
ALTITUDE	
	Up to 4600 Meters, above MSL (MIL-PRF-28800 Class 3)
SHOCK AND VIBRATION	
	Conforms to MIL-PRF-28800 Class 3

TABLE 1: THERMOCOUPLE ACCURACY (TYPICAL)

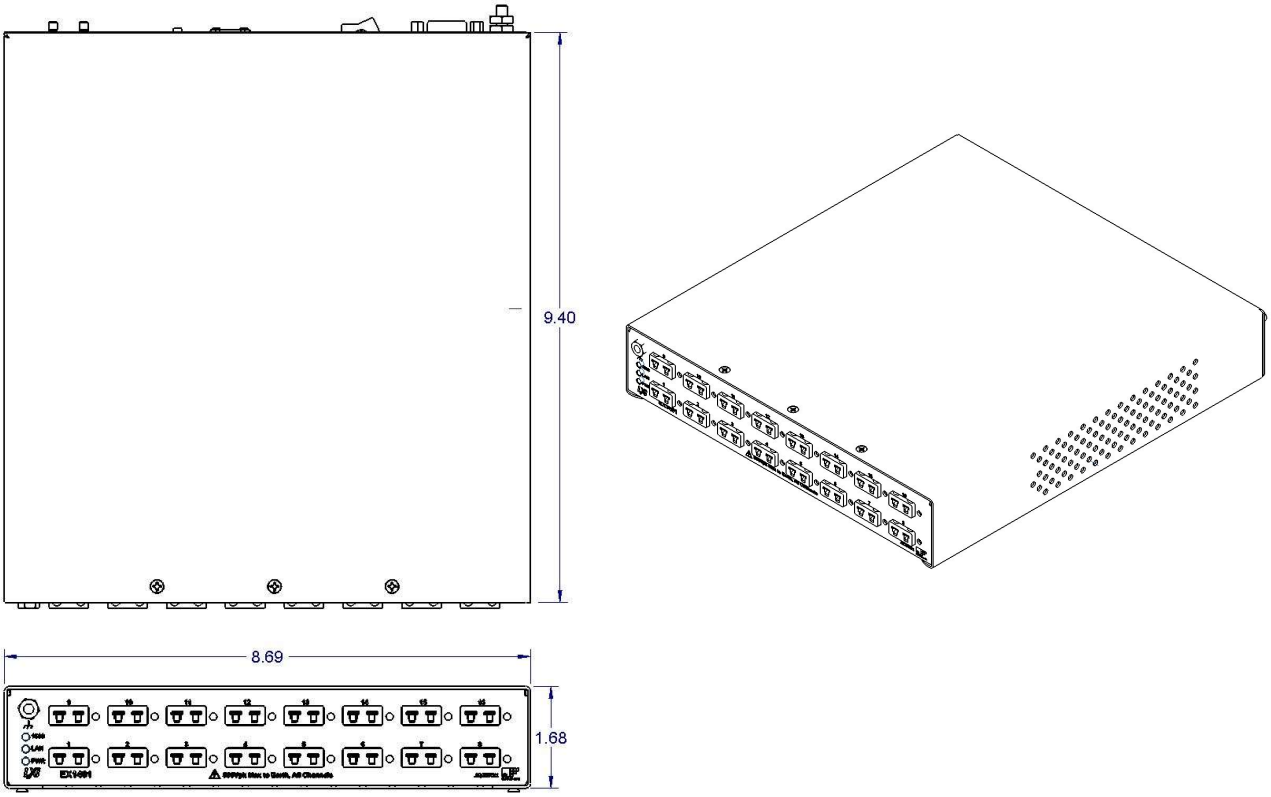
Type	Min	Max	-100	0	100	300	500	700	900	1100	1400
J	-200	1200	±0.25	±0.20	±0.20	±0.25	±0.30	±0.30	±0.35	±0.45	
K*	-200	1372	±0.25	±0.20	±0.20	±0.20	±0.35	±0.35	±0.45	±0.55	±0.50
T**	-200	400	±0.25	±0.20	±0.20	±0.20	±0.25				
E	-200	900	±0.25	±0.20	±0.20	±0.20	±0.25	±0.30	±0.35		
S	-50	1768		±1.00	±0.75	±0.65	±0.65	±0.65	±0.70	±0.70	±0.75
R	-50	1768		±1.00	±0.75	±0.60	±0.60	±0.60	±0.60	±0.65	±0.70
B	250	1820				±1.65	±1.10	±0.80	±0.70	±0.65	±0.65
N	-200	1300	±0.40	±0.25	±0.25	±0.25	±0.30	±0.35	±0.40	±0.40	

Values in °C

Conditions
- 60 minute warm-up
- Guaranteed maximum limits are two times (2x) the typical values
- 20 °C to 30 °C, 1 year from full calibration
- Exclusive of thermocouple errors
- Exclusive of noise
- Common mode voltage = 0

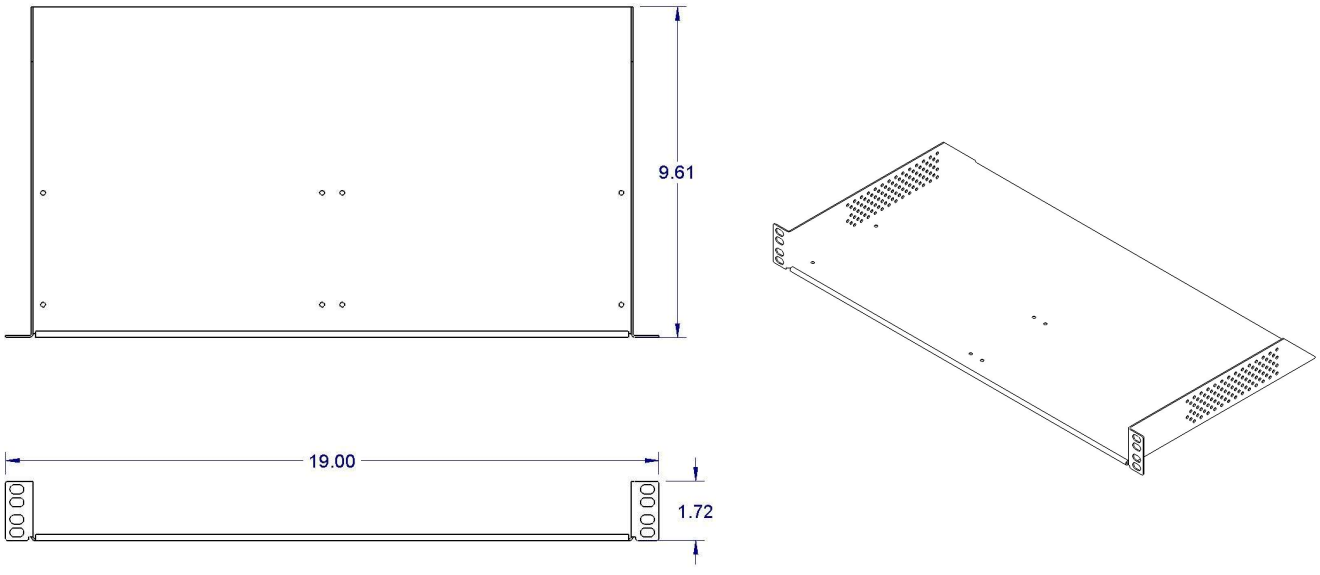
* 1400 accuracy is for 1372 °C
** 500 accuracy is for 400 °C

EX1401 Dimensional Diagram



Note: All dimensions are in inches

EX1401 Rack Mount Kit Dimensional Diagram



Note: All dimensions are in inches

MAXIMIZING MEASUREMENT PERFORMANCE

This section discusses tips and procedures that can help maximize the actual performance realized with the EX1401 and aid the user in avoiding some common pitfalls associated with measurement.

Utilize self-test

Self-test should be conducted to check the working condition of measurement path, CJC thermistor and digital control section.

Allow for cold junction thermal stabilization

The performance of any thermocouple measurement instrument is largely determined by the stability of the cold junction sensing mechanism. For maximum accuracy and stability, the EX1401 is designed with a CJC sensor per channel. However, while this lowers the sensitivity to thermal disturbances, transient measurement errors are still possible under certain operating conditions. Awareness of these conditions will help achieve the maximum performance from the EX1401. Some of the common sources of such thermal disturbance include steep changes in ambient temperature and insertion of the input connector.

Select the proper filter

The EX1401 provides flexibility to choose from different types of digital filters and also facilitates the customization of same. This provides large combination data rates, filter types, group delays, data latency, and decimation settings. Unless the bandwidth of the sensor requires a higher instrument bandwidth, prefer lower frequency spans using FIR filter, as it provides the greater immunity to external electrical and magnetic interference. Use of the Blind decimation stage directly (without any filter) is not recommended, since the spectral purity of output would be poor. Choice of the proper filter must be optimized for a given application, and same filter would not fit all applications.

Choose an appropriate sampling rate

For best instrument noise performance, the sampling rate should be set as low as the data collection requirements allow. For more details, see *Sampling Rate* / in Section 3.

Select proper location for installation

The EX1401 unit should be located away from sources of high or low temperature, strong air currents, and high magnetic fields.

Use correct wiring

Best results will be achieved with the shortest and thickest thermocouple wire that the physical requirements of the application can support. In addition, shielded thermocouples can be employed to raise the system's rejection of electrical interference. For more details, see *Input Connections / Wiring* in Section 2.

SECTION 2

PREPARATION FOR USE

UNPACKING EX1401

When the EX1401 is unpacked from its shipping carton, the contents should include the following items:

- EX1401 Precision Thermocouple & Voltage Measurement Instrument
- LXI Quick Start Guide
- EX1401 User's Manual (this manual)
- VTI Instruments Corp. Drivers and Product Manuals CD
- Agilent IO Library Distribution CD
- Auxiliary Power Adaptor (Optional)

All components should be immediately inspected for damage upon receipt of the unit.

CD Contents:

- LXI Quick Start Guide
- EX1401 User's Manual (this manual)
- Product Drivers and Product Manuals CD
- Agilent IO Library Distribution CD
- EXLab Software/Manual (Optional)

It also contains IVI shared components required to be installed for the device identification purpose. The LXI discovery utility provided on the CD is helpful to discover the EX1401 and other LXI devices connected in the network.

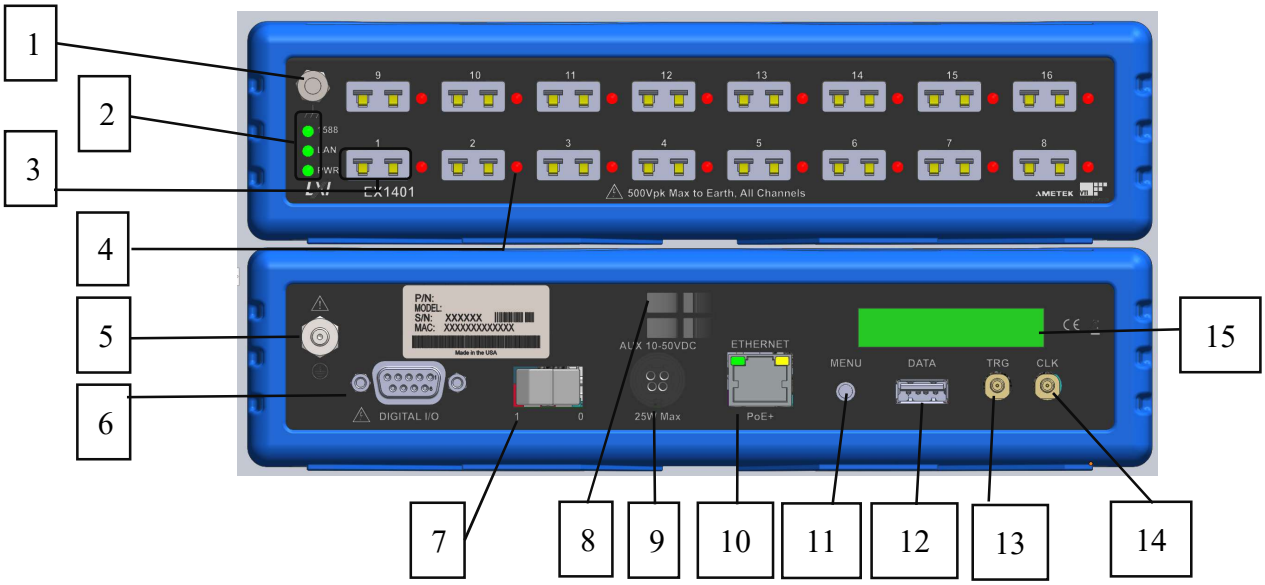
INSTALLATION LOCATION

The EX1401 is designed to be largely insensitive to external electrical, magnetic, and thermal disturbances. However, as with all precision instrumentation, certain precautions, if taken into consideration, can help achieve maximum performance.

1) The unit, particularly its front panel, should be located away from sources of high or low temperatures. When used in a rack-mount application with other heat-generating instruments, the EX1401 should be located as far away from the other instruments as possible, 1U minimum. Multiple EX1401s, however, can be stacked directly on top of one another without any performance degradation.
2) The front panel of the EX1401 should not be exposed to strong air currents. Typical problematic sources include building ventilation and instrument or cabinet fans.
3) The unit should be located away from sources of high magnetic fields such as motors, generators, and power transformers.

LOCATION OF CONNECTORS

Given below are the locations of various buttons, indicators and connectors on EX1401.



1. Earth point socket (standard Banana socket)
2. LXI System status indicators
3. Input connector (Mini Thermocouple Socket Cu-Cu)
4. Open thermocouple fault indication LED
5. Chassis Earth point stud, Safety ground
6. Digital IO port (Standard D-Sub 9 pin Female / Socket)
7. Power Switch
8. Cooling fan exhaust
9. Auxiliary power connector
10. Ethernet / LAN Port (PoE+ enabled)
11. Menu Button
12. USB 2.0 host port (Type A Female) for external data logging disk drive
13. Trigger Connector (Standard SMB Male)
14. External Clock Connector (Standard SMB Male)
15. Display

INSTALLATION OPTIONS

The EX1401 can be optionally rack mounted, using the rack mount kit accessory (P/N: 70-0626-900). This must be installed prior to installation into the rack. This option is not included with the EX1401 and must be ordered separately, if needed.

Rack-shelf Installation Option of EX1401

The shelf/tray installation option includes all the parts necessary to mount the EX1401 to the front of a standard test rack.

Required Tools

1) #2 Phillips screwdriver

Parts List

Item#	Qty	Description	VTI P/N
1	1	Bracket, Rackmount, EX1401 Chassis	70-0626-900
2	4	Screw, 4-40 x 3/16", Flat 82° Undercut Phillips, Black Oxide	

Assembly Procedure

1) Place the chassis on a protected work surface with its input connectors facing front.
2) Using a #2 Phillips screwdriver, install the rack shelf/tray on the bottom of the EX1401 using four (4) 4-40 x 3/16", Flat 82° Undercut Phillips, Black Oxide screws, as shown in below diagram.

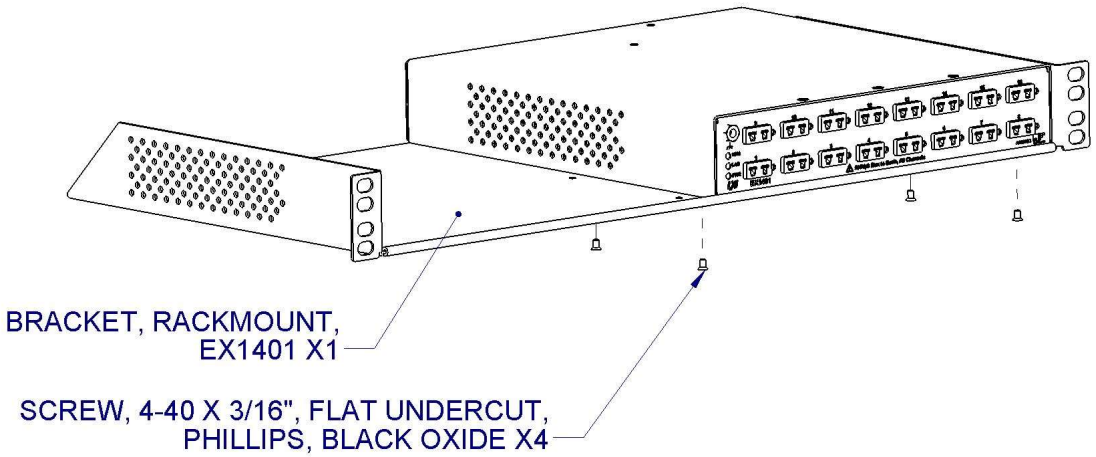


FIGURE 2-1: RACK SHELF INSTALLATION DIAGRAM

Tabletop Installation Option

The tabletop installation option can be used when the EX1401 is will not be installed in a rack, but will be employed as a bench top or desktop instrument.

Required Tools

1) #2 Phillips screwdriver

Parts List

Item#	Qty	Description	VTI P/N
1	4	Screw, 6-32 x 3/8", Pan Head Phillips	41-0620-003
2	2	Bezel, Cap, EX1401 Chassis	

Assembly Procedure

1) Place the chassis on a protected work surface, upside down, with its input connectors facing front.
2) Using Figure 2-2, locate the installation locations (on the bottom of the chassis) for each rubber cap bezel.
3) Using the #2 Phillips screw driver, install the four rubber feet using four (4) 6-32 x 3/8" pan head Phillips screws to secure the bottom.

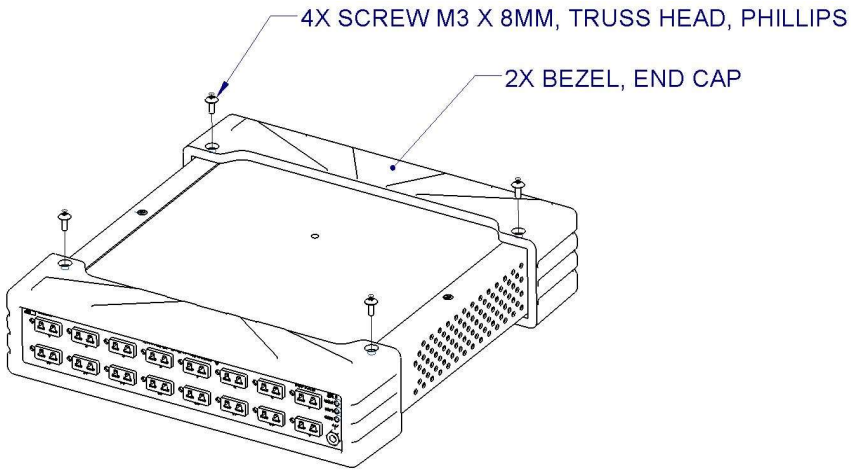


FIGURE 2-2: TABLE TOP FEET INSTALLATION DIAGRAM

WARM-UP TIME

The specified warm-up time of the EX1401 is 60 minutes. If, however, the unit is being subjected to an ambient temperature change greater than 5 ºC, extra stabilization time is recommended to achieve maximum performance.

POWERING UP AND GROUNDING

The EX1401 is designed to be powered by DC power source. It can be provided by either using a PoE+ enabled Ethernet port (which injects DC power into the network lines, such that there is no need of additional wiring), or through an external DC power adaptor. Many PoE+ enabled switches are compatible with EX1401. Some of the PoE+ switches that have been tested for compatibility are listed below.

- Cisco SF302-08PP (8-port PoE+ managed switch)
- Intellinet Model 560856 (8-port PoE+ switch)
- Trendnet TPE-115I/A (Power Injector)

The maximum power consumption of the unit is 15W. The unit accepts and performs within the specifications, when the Auxiliary Supply voltage is between +10V_{DC} to +50V_{DC}. The power inputs are protected for reverse polarity for up to 50V in reverse direction.

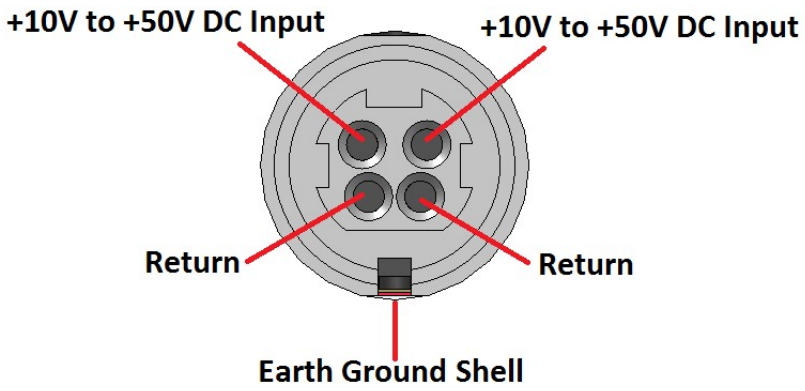


FIGURE 2-3: AUX DC IN CONNECTOR PINOUT

The power inputs (both POE+ and AUX DC IN) are isolated from chassis, as are the analog inputs and digital IO. Hence users are required to earth ground the EX1401 chassis for safe operation. The safety ground connection is on the rear panel and is required to be connected to the local earth ground using the provided cable (VTI# 53-0070-072). Do not use the banana jack on the front panel for earth grounding the EX1401. This connector is for reference only, and not intended for safety ground connection. The front side connector is a standard Banana socket (ITT Pomona 3267), while the rear side connector is 10-32 size stud.

SOFTWARE INSTALLATION

The fastest way to begin controlling an EX1401 is to discover the unit using the LXI Discovery Tool utility (a free tool available from LXI Consortium). For more information, refer to: http://lxistandard.org/Resources/LXIDiscoveryTool.aspx

The **LXI Discovery Tool** searches for all LXI Devices on the LAN Subnet. It uses mDNS and VXI-11 protocols to detect the LXI Instruments. You could optionally be asked to download "Apple Bonjour Print Services", if you would like to use mDNS service as the discovery mechanism. However, it is not mandatory to install this service, since LXI devices use various other protocols and services for discovery.

DRIVER INSTALLATION

VTI Instruments provides two types of drivers for this instrument. For Windows there is an IVI driver, based on the industry standard IVI driver architecture specifications. The IVI driver exposes both IVI-COM and IVI-C interface APIs. The IVI-COM interface can be used from any programming language that supports Microsoft COM (Component Object Model). For Linux, there is a driver that provides a C++ API. Both Windows and Linux drivers have a consistent API design so that the application software developed for one can be easily migrated to the other. The drivers are compatible with both 32-bit and 64-bit operating systems. In general, the API descriptions in this document apply to both the Windows and Linux drivers unless otherwise specified.

To control the EX1401 series instruments programmatically (via a user generated program or through tools such as Agilent VEE®, NI LabVIEW®, Mathworks Matlab®, etc.), two additional

components must be installed: the IVI Shared Components library (for Windows OS only) or the VTI Common Library (for Linux OS only) and the provided VTI Instruments driver. For 32-bit Windows OS, install the 32-bit driver. For Windows 7 (64-bit), Windows 8 (64-bit), and Windows 10 (64-bit), the 64-bit driver installer includes both 64-bit and 32-bit compatible drivers. These drivers are available for free download on the VTI Instruments web portal (www.vtiinstruments.com), in the respective product page, under download tab. The following sections describe installing the required software.

IVI Shared Components Installation (Windows Only)

If this component was installed during a previous LXI instrument installation, please proceed to Instrument Driver Installation. First, close all other open programs, leaving only Windows Explorer open. Navigate to the `<CD-ROM Drive>:\EX Platform Requisites` directory on the CD and run the `IVISharedComponentsX.X.X.exe` program. Next, follow the on-screen instructions. Do not proceed to the next step until this installation completes successfully. If instructed to reboot the PC, it will be necessary to do so at that time. Alternatively, the latest IVI shared components can be downloaded and installed from IVI Foundation Web page, www.ivifoundation.org.

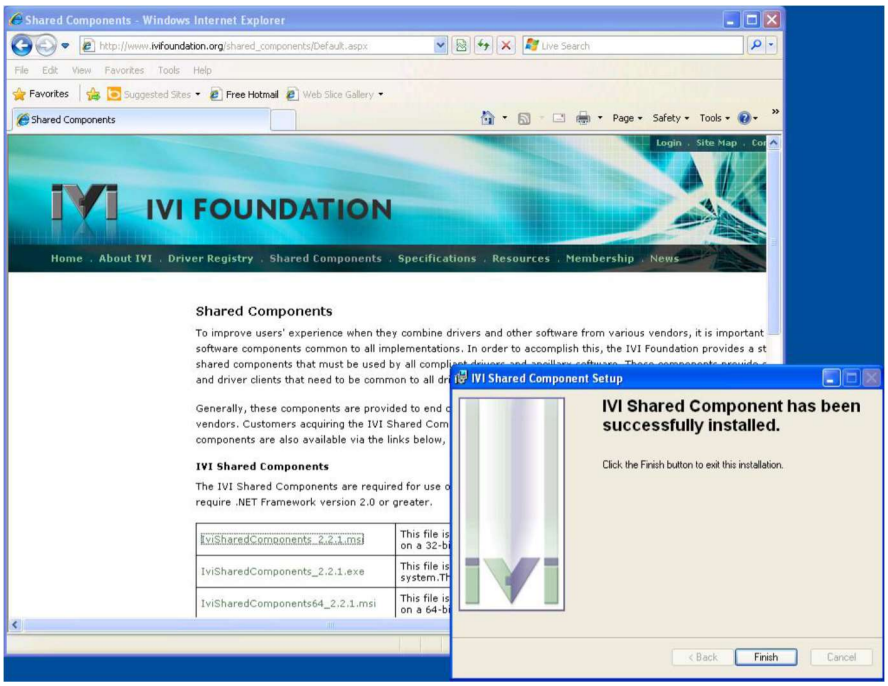


FIGURE 2-4: IVI SHARED COMPONENT INSTALLATION

Instrument Driver Installation

If the VTEXDigitizer instrument driver was installed previously on the host PC, you may skip this step of the installation process, and proceed to Platform/LXISync Instrument Driver Installation. The previously installed driver may need to be updated to the most recently released version to support the EX1401. To install the VTEXDigitizer instrument driver, navigate *to* `<CD-ROM Drive>:\Drivers\LXI Drivers\EX Series`, on the CD, open the appropriate zip file in this directory, and then run the `.msi` installer. Alternately the drivers are available for free download from VTI Instruments online portal (www.vtiinstruments.com) under the specific product's download page.

FIGURE 2-5: INSTRUMENT DRIVER INSTALLATION

The Linux driver (32-bit and 64-bit) is located under `<CD-ROM Drive>:\Drivers\Linux Drivers\Linux EX Series`. Open the appropriate zip file in this directory and then run the RPM Installer. Alternately the instrument drivers for Linux OS are also available for free download from VTI Instrument website (www.vtiinstruments.com)

Platform/LXISync Instrument Driver Installation

NOTE	**Complete this step only if the LXISync capabilities of the EX platform are required. If this driver was installed previously on the host PC, software installation is now complete.**

To install the Platform/LXISync Instrument driver, navigate to *<CD-ROM Drive>:\LXI Drivers\EMX Platform Driver, IVI* on the CD and run the .msi installer located in this directory. Please refer to the VTEX Digitizer Driver's online help file for programming guidelines. Additional information about IVI drivers can be found on the web at http://ivifoundation.org. Information about the LXI standard and LXI technology can be found at http://www.lxistandard.org.

NETWORK CONFIGURATION

By default, the EX1401 will attempt to locate a DHCP server. If one is found, the IP address assigned by the DHCP server will be assumed. Otherwise, after a timeout of 20 seconds, the unit will attempt to obtain an IP address by using Auto IP.

Auto IP is a mechanism for finding an unused IP address in the range 169.254.X.Y where X is in the range 1 - 254 and Y is in the range 0 - 255. The device will first attempt to obtain the specific address 169.254.X.Y, where X and Y are the second-to-last and last octets of the device's MAC address. However, X will be set to 1 if it is 0 in the MAC address, and to 254 if it is 255 in the MAC address. If this address is already in use, the unit will attempt to obtain other IP addresses in a pseudorandom fashion until it finds one that is available.

To illustrate the Auto IP mechanism, Table 2-1 lists the Auto IP default address for some example MAC addresses.

MAC Address	Auto IP Default Address
00:0D:3F:01:00:01	169.254.1.1
00:0D:3F:01:01:01	169.254.1.1
00:0D:3F:01:A3:28	169.254.163.40
00:0D:3F:01:FE:FE	169.254.254.254
00:0D:3F:01:FF:FE	169.254.254.254

TABLE 2-1: AUTO IP DEFAULT ADDRESS ASSIGNMENT

If a static IP address assignment is preferred, one can be optionally assigned via the embedded web page interface. This is done by clicking the **Network Configuration** link, disabling DHCP, and then assigning a static IP address.

However, a much more convenient and recommended way to obtain the benefits of a static IP address is to employ DHCP, but assign the instrument a reserved IP address in your company's DHCP server configuration. This reserved address, linked to the EX1401's MAC address on the DHCP server, would be assigned to the EX1401 at power up initialization without having to manually set it on the EX1401. The DHCP server configuration provides a centralized, controlled database of assigned IP addresses, preventing accidental assignment of the same IP address to multiple instruments. Consult your company's Information Technology department for assistance.

VXI-11, and mDNS Device discovery methods are supported by the EX1401. This allows all EX1401s on a local network to be found without knowledge of their MAC address or IP address with the use of a broadcast message. Also, the LCD display on the EX1401 provides the current IP Address configuration of the instrument, at any given instant. Refer to IPv4 Address section for more details on LCD menu operation.

Network Configuration Reset for EX1401

There is no dedicated network reset button on the EX1401. The "menu" button cycles through different screens on the LCD display. On the LAN Reset page, holding the menu in for more than 4 seconds will initiate a LAN Reset. The screen counts down as you hold in the button, and releasing the button during this stage will abort the reset operation.

The LAN Reset is useful for recovery from an incorrect or unknown network configuration. Note that the LXI reset function is not a processor reset or reboot. Initiating a LAN Reset will:

1) Enable DHCP and AutoIP
2) Disable Static IP
3) Set the mDNS hostname and service name to the last user-configured values, or the factory default values if the user hasn't changed those values
4) Enable IPv6
5) Remove the password (if any)
6) Set the time source to PTPv2 (if it was set to Manual or NTP)
7) Set the LXI event domain to 0

NETWORK TROUBLESHOOTING

If an error occurs, when trying to discover the EX1401 you may refer to**Error! Reference source not found.** "Common Issues" section in "**Error! Reference source not found.** If none of these resolutions help resolve the network connectivity issue, it may be necessary to change the network settings for the EX1401 and the host PC. By using the following methodology, most network-related issues can be resolved:

1) Navigate to the network configuration page on the LCD screen using the menu button
2) Note the current IP address and subnet details which are currently assigned to the instrument
3) Note the current network configuration of the PC, and get ready to change the IP address

4) Change the IP address of the PC, such that it will be compatible with EX1401 network
5) Disable all network interfaces (including WiFi) except that wired network, which is connected to the EX1401 mainframe
6) Connect the EX1401 to PC directly through Ethernet cable. Since EX1401 supports auto MDI-X feature, either Direct cable or Cross cable can be used to connect to the PC.
7) Open the embedded SFP webpage, of EX1401 and navigate to Network Configuration page
8) Make changes to the network as you need, and remember to "submit" the changes
9) Power cycle the EX1401 instrument
10) You can now disconnect the EX1401 instrument from PC, and change the PC Network configurations again, as needed.

Using Multiple Network Cards

When multiple network cards exist in a single PC, it may be necessary to define a static IP address to both the host PC NIC card that will interface with the EX1401 instrument as well as the EX1401 instrument itself. This process is only necessary if a DCHP server is not connected to the network to which the device is connected and typically occurs when the NIC is connected directly to the instrument.

The following process can be used to ensure proper functionality:

1) Navigate to **Start → Settings → Network Connections**.
2) Disable all network interfaces except the one that is connected to the EX1401 mainframe. This is done by right clicking on the interface, then selecting **Disable**.
3) Open the web page of the EX1401 mainframe.
4) Click the **IP Configuration** link. A prompt may appear to log into the EX1401 mainframe.
5) Unselect **DHCP** and **AutoIP** and ensure that **Static** is selected.
6) Enter an IP address into the **IP Address** field. For more information on valid IP addresses, please consult with an IT administrator.
7) Set the **Subnet Mask**.

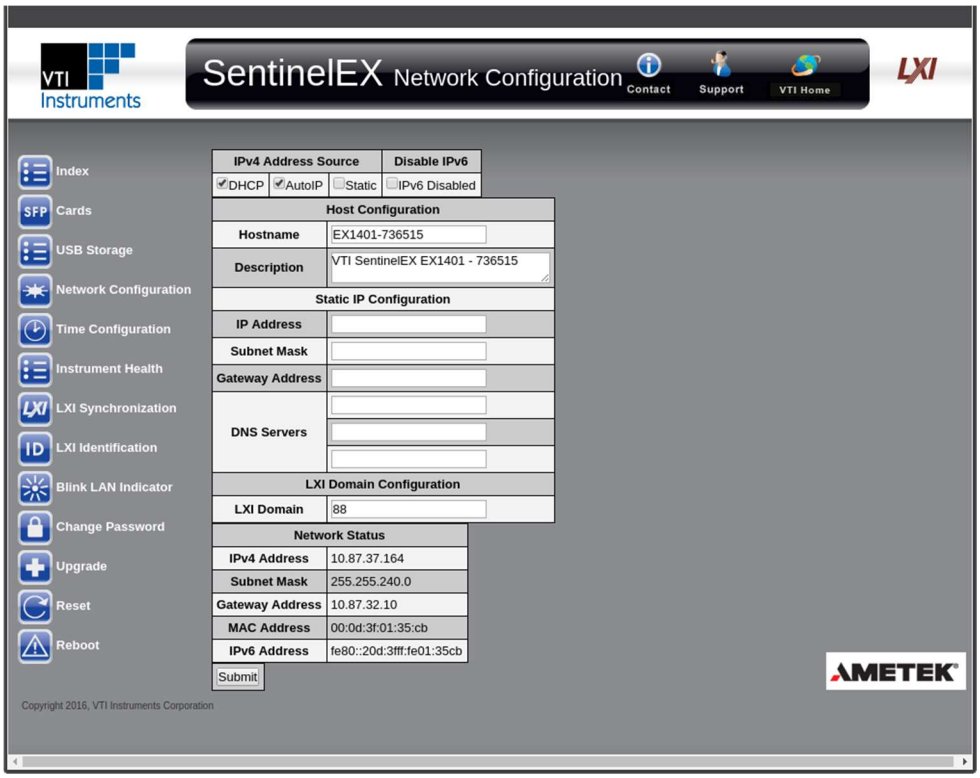


FIGURE 2-6: COMPLETED EX1401 MAINFRAME STATIC IP CONFIGURATION

8) Click the **Submit** button. Once this is done, it is no longer possible to communication with the EX1401 mainframe. This is normal and is addressed in the following steps.
9) Set a static IP address for the NIC card by doing the following:

   a) Navigate to **Start → Settings → Network Connections**.
   b) Right click on the NIC card that the EX1401 mainframe is connected to and select **Properties**.
   c) Select Internet Protocol (TCP/IP) and click **Properties**.

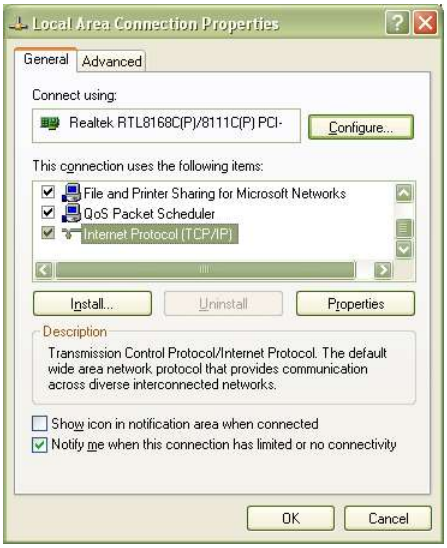


FIGURE 2-7: TCI/IP SELECTION

   d) Click the Use the following IP address radio button.
   e) Enter the desired IP address.
   f) If not automatically completed after the IP address is entered, set the **Subnet mask** field to suitable address range

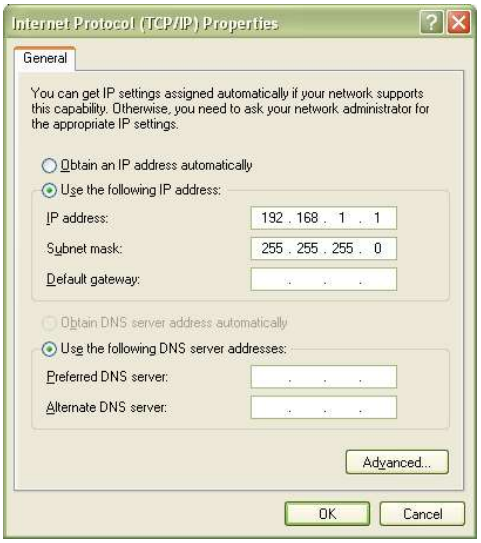


FIGURE 2-8: COMPLETED NIC STATIC IP CONFIGURATION

   g) Click OK to exit the network configuration properties.

TIME CONFIGURATION

By default, the EX1401 will be configured to receive its time through PTPv2 (Precision Time Protocol). The user can also set time using SNTP (Simple Network Time Protocol) or the time can be set manually. The manual setting is necessary if the network environment is such that the unit cannot reach the Internet / Intranet time server. For more information, see the **Error! Reference source not found.** in the **Error! Reference source not found.**

INPUT CONNECTIONS / WIRING

Thermocouple Connections

The EX1401 employs an uncompensated (Cu-Cu) mini-thermocouple female jack as its input connector. This connector provides a solid, reliable connection that is also easily changeable. Since it is not thermocouple-type specific, different thermocouple types can be mixed throughout the unit without hardware modification. The input jack is polarized and will only accept its mating connector in one orientation. The mating connector is a standard mini-thermocouple male jack. A popular source is the SMPW series from Omega Engineering. For specified accuracy performance, the input connector must be of the same thermocouple type as the wire being connected.

Thermocouple wire is polarized, and it is critical to consider this polarity when connecting the thermocouple wire to the thermocouple jack. For reference, the color designations and polarizations of the most popular thermocouple types are listed in Table 2-2 for both ANSI (American) and IEC (European) standards.

ANSI Thermocouple Standard				
Thermocouple	**+**		**-**	
Type J	White		Red	
Type K	Yellow		Red	
Type T	Blue		Red	
Type E	Violet		Red	
Type S	Black		Red	
Type R	Black		Red	
Type B	Gray		Red	
Type N	Orange		Red	

IEC Thermocouple Standard				
Thermocouple	**+**		**-**	
Type J	Black		White	
Type K	Green		White	
Type T	Brown		White	
Type E	Violet		White	
Type S	Orange		White	
Type R	Orange		White	
Type B	Gray		White	
Type N	Pink		White	

TABLE 2-2: STANDARD THERMOCOUPLE REFERENCE DESIGNATIONS

In most applications, the length and gauge of the thermocouple wire do not affect the accuracy of the measurement. Due to the high input impedance and lack of switching in the signal conditioning circuitry of the EX1401, the resistance and capacitance of the thermocouple wire are normally not important factors. If, however, maximum system accuracy is desired, the resistance of the thermocouple wire must be considered as a system error source. As an example, 650 ft of 24 gauge type T wire has a resistance of about 500 Ω. Against the EX1401's typical input bias current of 5 nA, this creates a voltage error of:

$$500\Omega \times 50\text{nA} = 2.5\,\mu V$$

To convert this error to its representative temperature error, it is then divided by the slope of the thermocouple characteristic at the temperature of interest. For example, the slope of the type T characteristic at 0 ºC is 39 µV/ºC. The error at this point is then:

$$2.5\mu V \div 39\mu V/^{\circ}\text{C} = 0.064^{\circ}\text{C}$$

This example demonstrates how to evaluate the potential error that a specific wire installation represents. The user is encouraged to evaluate each individual application to ensure that the error is

within acceptable bounds. In general, best results will be achieved with the shortest and thickest wire that the physical requirements of the application can support.

The EX1401 offers excellent noise rejection through its high common mode rejection and selectable bandwidth limiting, which allows for high integrity, noise-free measurements with even less-than-ideal wiring setups. However, some common instrumentation wiring practices can be used to achieve or ensure maximum performance.

Shielded thermocouple wire can be used to raise the system's rejection of electrical interference. Shielded wire encloses the two thermocouple wires with a low impedance conductor that should be terminated by the user to a convenient earth ground. The EX1401 provides an external ground stud that can be used for this purpose, but any earth ground point is acceptable.

Magnetic interference, which is present wherever high currents are flowing, is conversely decreased by minimizing the loop area represented by the two thermocouple wires. That is, the wires should be run closely together from the thermocouple junction to the connections in the thermocouple jack. Fortunately, most thermocouple wire comes with a sheath that covers the two thermocouple conductors, inherently creating a small loop area.

Many test applications involve the monitoring of a test article in a chamber, requiring the routing of numerous types of signals through the chamber's cable access ports. It is recommended that the thermocouple wires be run through a separate port and conduit from cables carrying power or high frequency signals.

Voltage Connections

Each input channel of EX1401 can be independently configured to measure differential voltage signals. Since the EX1401 employs an uncompensated (Cu-Cu) mini-thermocouple female jack as its input connector, measurements are not affected by the thermocouple effect. Users are recommended to use suitable Cu-Cu mini thermocouple male plugs, with proper polarity. A popular source is the SMPW series from Omega Engineering.

Note: The Cu-Cu type uncompensated thermocouple hardware is sometimes called as Type-U or Calibration type. They will be generally available in White Color. The Thick pin represents the negative polarity, while the thin pin is marked for positive polarity.

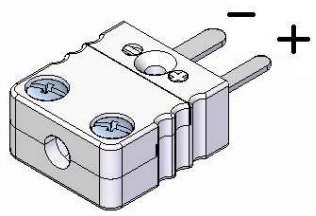


FIGURE 2-9: VOLTAGE CONNECTOR POLARITY IDENTIFICATION

SECTION 3

BASIC OPERATION

INTRODUCTION

This section expands on the description of the EX1401's features and explains how to best use them.

ENGINEERING UNIT (EU) CONVERSION

Each EX1401 input channel can be individually configured for measuring thermocouples or voltage. The following thermocouple types are supported:

Voltage	The instrument will return the raw voltage measured at its input with units of volts (V). It is unaffected by the measured or input CJC temperature for that channel.
Type J, K, T, E, S, R, B, N	The instrument will return the compensated thermocouple temperature measured at its input with units of temperature (ºC or ºF). The thermocouple calculations are performed using the full-order polynomial equations and coefficients from the NIST ITS-90 Thermocouple Database.
Custom	The instrument will return the compensated thermocouple temperature measured at its input with units of temperature (ºC or ºF). The thermocouple calculations are performed using user-defined coefficients for the polynomial equations. More information on this is given under *User-defined Conversions*. The custom coefficients can be unique for each channel.

The default selection is voltage.

NOTE	**In a mixed thermocouple system, it is very easy to accidentally mismatch the hardware setup and the software configuration setup. Care is especially warranted, as the resultant errors may not be large enough to obviously indicate a problem, but may be significantly larger than the accuracy specification of the instrument.**

Linear Correction

The EX1401 provides the capability to apply a linear transformation on voltage-mode measurement data after EU conversion. Each channel can be programmed with a gain and offset which are applied as (gain*data) + offset.

Gains default to 1.0 and offsets default to 0.0.

VOLTAGE MEASUREMENT RANGES

The EX1401 provides ±0.01 V, ±0.10 V, ±1.0 V, and ±10.0 V voltage measurement ranges on all input channels. Channels which are configured for thermocouple inputs will use ±0.10 V range. Voltage measurement range is programmable on a per-channel basis.

The default selection for voltage channels is the ±10 V range.

HARDWARE / ANALOG ANTI-ALIAS FILTER

Each EX1401 input channel has a fixed, 2-pole, 12kHz RC low pass filter for anti-alias filtering. The analog signals after the anti-alias filter are over sampled at 320kHz to 640kHz by the ADCs. This combination of anti-alias filter with ADC oversampling provides 60dB of rejection at the aliasing band.

DIGITAL FILTER

The EX1401 allows the user to configure different types of digital filters per channel. These digital filters are implemented inside the FPGA of the device, such that they perform consistently and without loading the host computer resources. Users can optimize the filter settings for aggressive filter performance or lower data latency time. In addition, users can customize the FIR filter performance by editing the coefficients of the filter. This provides ultimate flexibility in designing a filter to suit the application needs. The digital filter parameters for each channel can be defined independently. Final data throughput is a complex parameter and depends on the basic sampling rate and digital filter selection. Choosing the correct sampling rate and digital filter parameters is critical for achieving optimum performance levels of common model signal rejection, roll-off rate, and data latency. Please refer to “Sampling Rate / Filter” section for more details.

Below table provides quick summary of selection criteria, for common applications:

Application Factor	2^n FIR	CIC / CIC+FIR	Blind Decimation
Sampling rate flexibility	√		
Latency or group delay		√	√
Gibbs phenomena (Impulse response)		√ [1]	√ [2]
Passband freq to sampling freq ratio	√	√	√
Stopband attenuation/alias rejection	√	√	
Passband ripple	√	√	√
Group delay linearity	√	√	√
FPGA utilization	√	√	√

TABLE 3-1: TYPICAL CRITERIA FOR SELECTION OF DIGITAL FILTERS

1. When used with sloppy CIC+FIR (CIFR) filter

2. Unless care is exercised, ADC may end up ringing heavily

MEASUREMENT RANGE / INPUT PROTECTION

The specified input voltage range of the EX1401 thermocouple channels is up ±10V for voltage measurements. This level refers to the maximum differential voltage, or voltage that is applied between the (+) and (–) input terminals, that can be measured without distortion, and range where the specifications are guaranteed. The native input range of amplifier is actually ±14.4V, but the outer 4.4V is left out since the performance in this region will not be linear.

The measurement range of the EX1401 in terms of temperature is a function of its input voltage range and the capabilities of the thermocouple sensors themselves. Specifically, the measurement range of the EX1401 for the standard thermocouple types is the following:

Type	Min (°C)	Max (°C)	Min (°F)	Max (°F)
J	-210	1200	46	2192
K	-200	1372	-328	2502
T	-200	400	-328	752
E	-200	1000	-328	1832
S	-50	1768	-58	3214
R	-50	1768	-58	3214
B	250	1820	482	3308
N	-200	1300	-328	2372

TABLE 3-2: EX1401 MEASUREMENT RANGE

The maximum common mode voltage (the voltage level, that is applied to the + and – inputs together, with reference to chassis ground), that can be applied without causing out-of-specification distortion of the differential measurement is ±500 V_{PEAK}. Application of differential voltages exceeding ±10V level will result in measurements reported as the floating-point representation of NaN (Not a Number). The instrument will be damaged permanently, if differential voltage, across any channel, exceeds ±100 V_{peak}.

NOTE The application of differential voltages beyond ±100 Vpeak may permanently damage the EX1401.

All inputs are protected from EMI, using 1nF feed through capacitors to chassis ground. Also they are protected from accidental electro static discharges (ESD): 6V Unidirectional TVS IEC61000-4-2, ±8kV Contact, ±10kV Air

COLD JUNCTION COMPENSATION (CJC)

For highest accuracy and stability, the EX1401 provides embedded isothermal input sections that are monitored by high precision thermistors, one for each thermocouple input channel. Although internal compensation capabilities are present, it is still possible to disable this feature and define CJC temperatures externally. To ensure that CJC information is current and time correlated with the input channels, CJC channels are measurements are synchronized with input sampling clock, providing a maximum time separation of less than 4 ms between the input channel measurement and its associated CJC measurement. Internal CJC channels are measured via a separate 16-bit ADC, which is synchronously clocked at fractional rate of channel sampling clock.

NOTE The health of internal CJC channels is verified during instrument self-test of EX1401

The user has configuration control over the reporting of the measured CJC data. This control only affects the display of their data, not the actual measurement of them. They are updated with every scan, regardless of their reporting status.

The EX1401 also accommodates the use of an external cold junction that is maintained and measured by the user. In this application, the cold junction temperature in ºC is entered into the EX1401 and enabled on a per channel basis. That is, the use of internal and user-defined CJC inputs can be mixed throughout the unit.

The default selections are:

- CJC reporting is disabled
- User-defined CJC temperatures are 0.0
- User-defined CJC temperatures are disabled for all channels

TEMPERATURE UNITS

The EX1401 can output its temperature data with units of ºC or ºF. This is controlled on a global basis, such that all input channels are configured with one setting. This selection applies to input

channel data only. Input channels configured for an EU conversion of voltage are unaffected by this setting.

The default selection is °C.

SAMPLING RATE / FILTERS / NOISE FLOOR

The EX1401 supports a large range of sampling rates, due to its flexible ADC sampling clock and programmable digital filters. Sampling rate is dependent on the decimation filters performance expectation, and latency of first data that can be tolerated by your application. Figure 3-1 represents the general architecture of the EX1401 ADC and filter scheme.

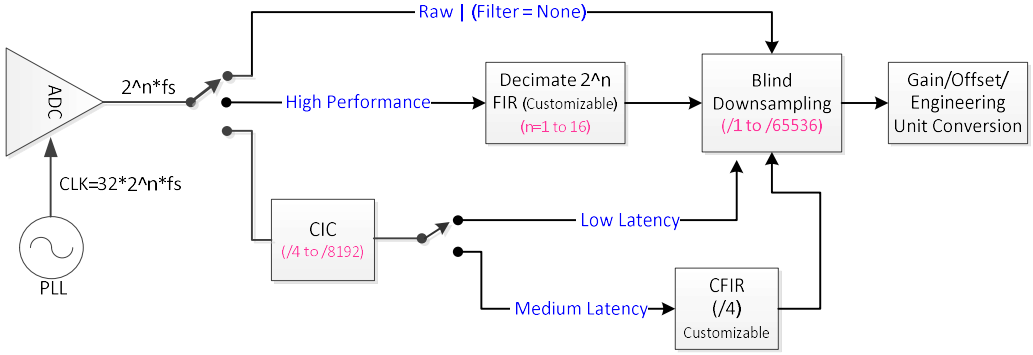


FIGURE 3-1: ADC AND FILTER SCHEME

It is possible to specify the sampling rate two ways. In the first method you can specify each parameter of the data decimation chain; including ADC Sample clock frequency, filter type and configuration, downsampling factor etc., to produce a required data output rate. In the second method you may simply specify the final data sample rate (or the frequency span of interest), and desired filter type, such that all other dependent parameters will be automatically adjusted, to produce output at desired sample rate.

The noise floor performance of the system also depends heavily on the decimation rate, since higher decimation factors will help improve the signal-to-noise ratio. Given below are typical noise level performance specifications at various input voltage ranges.

Voltage Range	Full Scale V_{in}	Decimation factor	V_{Noise}	S/N Ratio (dB)
±100mV	100mV	1	54.3 x10^{-6}	65.3 dB
±100mV	100mV	10	17.2 x10^{-6}	75.3 dB
±100mV	100mV	100	5.4 x10^{-6}	85.3 dB
±100mV	100mV	1000	1.7 x10^{-6}	95.3 dB
±100mV	100mV	10000	543 x10^{-9}	105.3 dB
±1V	1V	1	135.3 x10^{-6}	77.4 dB
±1V	1V	10	42.8 x10^{-6}	87.4 dB
±1V	1V	100	6.8 x10^{-6}	103.4 dB
±1V	1V	1000	4.3 x10^{-6}	107.4 dB
±1V	1V	10000	1.4 x10^{-6}	117.4 dB
±10V	10V	1	1.7 x10^{-3}	75.6 dB
±10V	10V	10	525.5 x10^{-6}	85.6 dB
±10V	10V	100	166.2 x10^{-6}	95.6 dB
±10V	10V	1000	52.5 x10^{-6}	105.6 dB
±10V	10V	10000	16.6 x10^{-6}	115.6 dB

TABLE 3-3: VOLTAGE MEASUREMENT NOISE PROFILE VS. DECIMATION (SAMPLING RATE)

OPEN TRANSDUCER DETECTION / OVERLOAD CONDITIONS

The EX1401 provides the ability to detect several different signal overload conditions, as well as several ways to report them. They are reported on a per-channel basis as a 32-bit mask of active conditions, via the Channel.Overload.Status property. The following bits are supported for the EX1401:

Bit Mask	Name	Description
0x00000002	Transducer Upper Limit	The signal is above the defined range of the transducer's EU conversion. This is either the limit of the NIST polynomials, for standard thermocouple types, or the user-supplied value of Channel.Tranducer.UpperLimit.
0x00000004	Transducer Lower Limit	The signal is below the defined range of the transducer's EU conversion. This is either the limit of the NIST polynomials, for standard thermocouple types, or the user-supplied value of Channel.Tranducer.LowerLimit.
0x00000008	User Upper Limit	The signal is above the user-defined value of Channel.Overload.UserUpperLimit, and Channel.Overload.UserLimitEnabled is True.
0x00000010	User Lower Limit	The signal is below the user-defined value of Channel.Overload.UserLowerLimit, and Channel.Overload.UserLimitEnabled is True.
0x00000020	Open Transducer	The OTD trickle current is enabled and has caused the input voltage to rise above the upper limit of the ADC's valid input range.
0x00010000	ADC Overload	The signal is outside of the ADC's valid input range, either too high or too low.
0x00100000	ADC Sync	The channel's ADC has become unsynchronized from the others in the instrument, likely due to electrostatic discharge. While this status bit remains set, the firmware is resynchronizing it.

TABLE 3-4: OVER LOAD CONDITIONS AND INDICATIONS

Any of these bits can be enabled to drive the state of the front-panel LEDs or any of the instrument's trigger outputs (EXT, DIO0-7, LAN0-7). For more information, see the "Overload and LEDs*"* and *"*Overload and Trigger Outputs*"* sections.

Any of these bits can also be enabled as latching. If this is set, the bit will only become unset in the status at the beginning of a new acquisition, or when explicitly cleared by the user.

Each block of data read from the instrument will include a single bit indicating whether any overload status bits were set for any of the included samples. This provides a simple, quick indication of whether the data is valid for a particular block.

OVERLOAD AND LEDS

Being an LXI standard compliant instrument, the EX1401 instrument provides 3 number of LED indicators in the front and rear side of instrument, to indicate the status of power, network connectivity and synchronization status.

Power LED (PWR):

This is a single colored LED. If the LED is glowing Solid Green, it indicates that power is applied to instrument, and is in active states.

LAN LED:

This is a Bi-color LED (Red/Green), used for indicating the basic network connectivity status. The LED glows in Solid green color, when the device is successfully connected to a network, without any conflict / error. If there is a problem with the LAN connectivity, this indicator turns to Solid red color. If the LED is blinking / flashing green color, it indicates that the Device Identification command was received over the LAN. The status indicator shall continue to flash green until commanded to do otherwise. Refer Blink LAN Indicator section under web page operation section for more details.

1588 LED:

The IEEE 1588 Clock Status Indicator is designed to show both the status and the type of clock in the EX1401 device. This indicator is a single, bi-color LED (Red/Green) whose states are identified as follows:

State of LED	PTP Clock / Sync State
LED Color (s)	Single (Greeen)
Off	Not Slave, Not Master, and Not Faulty
On – Solid Green	Slave
On – Blinking Green once every second	Master but not Grandmaster
On – Blinking Green once every two seconds	Master and also Grandmaster
On – Solid Red	Faulty

LEDs on Network Port:

There are two LEDs present on the RJ45 Ethernet connector, placed on the rear side of EX1401. The right-yellow LED indicates network activity. The blink rate is roughly proportional to amount of network traffic. The left-bicolor (green/amber) LED indicates connectivity and rate. Green indicates connected at 100Mbs and amber indicates connected at 10Mbs. If both LEDs are Off, it indicates that network is not connected. Network connectivity does not mean the device as obtained an IP address, and have access to connected network. The LAN indicator on the front provides that function.

Channel LED Indicators

In addition to the system status indicators, the EX1401 also features a red LED for each channel on its front panel, mounted next to the mini-TC connector. The behavior of this LED can be controlled by setting the Channel.Overload.Indicator property. This is a mask with the same bit values as the Overload Status described above. Whenever Channel.Overload.Status & Channel.Overload.Indicator != 0, the LED be will be lit. Otherwise, the LED will be off. By default, on the EX1401, only the OTD bit is set in the Indicator mask, so the LED will indicate open transducer status until configured otherwise.

OVERLOAD AND TRIGGER OUTPUTS

The EX1401 features three methods of trigger output: an 8-channel DIO port, an External trigger SMB, and 8 LAN Events. Any of these can be tied to the Overload status of one or more channels. First set the Channel.Overload.EventEnabled mask, which has the same bit definitions as the Channel.Overload.Status described above. Whenever Channel.Overload.EventEnabled & Channel.Overload.Status != 0, any associated trigger outputs will be driven high. Otherwise, they will be driven low.

To associate trigger outputs with channel overloads, the Events interface is used. Set the Source property of the desired trigger output's Event interface to Overload_CH<N>, where <N> can be either a single channel number or a range of channels. For instance, setting Events.Item["DIO3"].Source = "Overload_CH1,8,12-16" will cause DIO3 to be driven high whenever any of channels 1, 8, 12, 13, 14, 15, or 16 have any overload condition.

DIGITAL I/O

The EX1401 features an 8-channel digital I/O port on the rear panel of the instrument. This port can be used for various functions, such as arm/trigger source, for presentation of limit evaluation information, and as a general purpose input/output device. The digital I/O connector is a standard DB-9 with the following pin assignment:

Pin	Function
1	DIO Channel 0
2	DIO Channel 1
3	DIO Channel 2
4	DIO Channel 3
5	DIO Channel 4
6	DIO Channel 5
7	DIO Channel 6
8	DIO Channel 7
9	GND

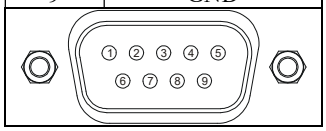


TABLE 3-5: DIGITAL I/O CONNECTOR & PIN ASSIGNMENT

As a general purpose output device, each DIO channel can be independently programmed with regards to its output functionality and its logic state, when enabled as an output. When not enabled as an output, a channel becomes tri-stated, preventing conflict with other potential voltage drivers. Refer the port's electrical specifications in Table 3-6 for voltage tolerance limits and output drive capabilities. Regardless of output functionality, each channel provides constant input functionality. That is, the input level on each channel can be accessed without a specific enable function call. Moreover, the base functionality of the DIO channels is not affected by triggering, data acquisition, or any other instrument process. It is also possible for the DIO data to be acquired and reported along with the analog channel data. Unless linked to a limit condition, as discussed below, the DIO port's operation is completely autonomous.

The default selections for each DIO channel are:

- output enable is off
- output level is 0

The electrical specifications for the digital I/O port are provided in **Error! Reference source not found.**. Particular note should be given to the V_{INPUT} specification of -0.5 V to 5.5 V. Exceeding that value with an external voltage source, even though a resistance, could permanently damage the EX1401.

Characteristic	Value
V_{INPUT}	-0.5 V to 5.5 V
V_{IH}	2 V min
V_{IL}	0.8 V max
V_{OH} (I_{OH} = -32 mA)	2 V min
V_{OL} (I_{OL} = 64 mA)	0.55 V max

TABLE 3-6: DIGITAL I/O PORT ELECTRICAL SPECIFICATIONS

The Digital IO port is bank isolated from chassis ground / earth potential for up to ±250VPEAK. However, there is no inter-channel isolation between digital channels. The Digital I/O port is ESD protected on all IO pins.

NOTE	Each Input channel of Digital IO port is pulled down through 10K Ohm resistor to its ground

TRIGGERING

The EX1401 supports a full function trigger model with a separate arm source and trigger source event structure. For a complete explanation of the trigger model, see refer “Start, Arm, Trigger, and Alarm” section in Chapter-5. In summary, an acquisition sequence is enabled with a trigger initialize command. Scanning is then initiated upon the receipt of the programmed arm source event followed by the receipt of the programmed trigger source event. Trigger and arm source events can be independently programmed from a variety of sources including Immediate, Software, External trigger, Digital I/O, LAN Events, and LXI alarms.

DATA FORMAT

By default, the data returned during data retrieval is limited to the channel readings and the absolute time of measurement initiation. If enabled, the EX1401 can also return the measured CJC temperatures.

ACQUIRING DATA

In general, the acquisition and retrieval of data on the EX1401 are conducted with discrete commands that are often separated in time to a large degree. The EX1401 utilizes a 256 MB FIFO memory storage to buffer acquisition data prior to retrieval. This reading buffer is cleared upon receipt of the trigger initialize command in preparation for reading storage, and begins storing new data in a circular buffer immediately. Then, upon fulfillment of the programmed trigger model conditions, the EX1401 marks one or more records in the circular buffer for user retrieval. It continues scanning and storing the acquisition data until the trigger and arm count quantities are reached or the acquisition is aborted. At that point, data acquisition ceases and the trigger model is returned to the Idle state.

The amount of scans records that can be buffered within the memory is dependent on the number of channels enabled and the requested record size. Specifically, the number of records that can be buffered (Record_Count) is determined by the following formula:

Sample_Size = 4
Record_Bytes = Record_Size * Sample_Size * (Channel_Count + DIO_Reporting)
Record_Count = 268435456 / Record_Bytes

where: Channel_Count 0-16 (number of channels enabled)
Record_Size 1-65527 (number of samples per record)
DIO_Reporting 0 or 1 (1 – YES, 0 – NO)

Regardless of the RecordSize, each channel’s circular buffer is then truncated to make its total size evenly divisible by 4096.

Record_Count sizes for some typical configurations are the following:

Channel_Count	DIO_Reporting	Record Size	Record Count
1	0	1024	65536
0	1	1024	65536
8	0	1024	8192
16	0	1024	4096
16	0	4096	
16	0	1	1024

16	1	1024	3852
16	1	4096	963

TABLE 3-7: EXAMPLE RECORD COUNT SIZES

If the circular buffer fills to the point that it would overwrite a record marked for retrieval by a trigger before it has been read out, the instrument will abort the acquisition and return to the Idle state.

NOTE The reading buffer memory is volatile and is cleared upon an instrument reset or power cycle.

RETRIEVING DATA

Acquisition data can be retrieved from the EX1401 with any of three methods. First, it can be manually read out of the instrument's FIFO sometime after it is measured. This method is the simplest, but runs the risk of aborting the measurement early if the data is not retrieved before the 256MB circular buffer is filled. The data can also be streamed to one or more endpoints. Streaming endpoints can include one instrument driver session and any number of attached USB storage devices. When streaming to the instrument driver is enabled, the instrument will send binary encoded data directly to the driver as soon as it becomes available. The instrument driver can then either buffer the data in PC memory for retrieval at the user's convenience, save the data directly to hard disk, or call a user callback with the new data. When a USB storage device is enabled for streaming data, the data will be written directly to the device as soon as it becomes available in the HDF5 file format.

In either case, retrieved data is fully calibrated and compensated by the EX1401 and output directly in the requested units. No post-acquisition user manipulations are required. In order to provide the maximum reading buffer capacity for future acquisitions, data is deleted from the FIFO memory upon retrieval.

Applications may retrieve data from this FIFO using either the Read FIFO or Streaming Data interfaces. Please refer to the Data Acquisition**Error! Reference source not found.** section of Chapter-5 for further details. Once data is retrieved from the FIFO, via any method, it is no longer kept within the FIFO.

USER-DEFINED CONVERSIONS

The EX1401 nominally accepts standard thermocouple types and performs its thermocouple calculations using polynomial coefficients from the NIST ITS-90 Thermocouple Database. In some applications, however, a user may want to override the embedded coefficients with a user-defined coefficient set. One reason to do this is if the transfer function of the specific thermocouple being used has been completely characterized to an accuracy level that exceeds standard thermocouple limits of error. Another reason to do this is if a non-standard thermocouple is used. One unique set of coefficients can be entered for each channel. Specifically, the use of custom thermocouple equations requires the user to know or generate the coefficients for two conversion polynomials.

The *forward conversion polynomial* is used to convert a CJC temperature into a compensating cold junction voltage and has the form of:

$$E = c_0 + c_1 * t^1 + c_2 * t^2 + \ldots + c_{12} * t^{12}$$

where E is in volts, t is in ºC, and c_0 - c_{12} are the coefficients.

The *inverse conversion polynomial* is used to convert a compensated input voltage into temperature and has the form of:

$$t = d_0 + d_1 * E^1 + d_2 * E^2 + \ldots + d_{12} * E^{12}$$

where E is in volts, t is in ºC, and d_0 - d_{12} are the coefficients.

The default values for the coefficients are [0.0, 1.0].

NOTE	The entry of user-defined coefficients does not automatically enable their use. The enabling is done by setting the Thermocouple Type to "Custom".

LCD DISPLAY

The display on the rear side of EX1401 is a 20 x 2 backlit LCD. It can display several screens that can be cycled through using the Menu button. Some screens allow you to initiate an action. This is done by holding the menu button in for several seconds. A countdown of remaining seconds is shown while the button is pressed. The action is activated on release of the menu button; releasing before the countdown completes will cancel the action. Screens with actions are LAN Reset, Self Test, USB Eject, and USB Data Logging.

Hostname

```
Hostname
EX1401-681514
```

IPv4 Address

```
IPv4 Address
10.87.37.24
```

If the device does not have an IPv4 address, the display will show "Network unavailable" instead of the IPv4 address.

```
IPv4 Address
Network unavailable
```

IPv6 Addresses

The IPv6 address screens show one or two addresses on two or three screens. Because an IPv6 address is too large to fit on a screen the addresses are split between the HostID, which is the lower 64-bits, and the Subnet, which is the upper-64 bits. If the device does not have a global IPv6 address, it will show as "Network unavailable". If IPv6 is disabled, then all IPV6 screens will show "Network unavailable". Note that the HostID portion is common to both the Local and Global addresses and so is only displayed once.

```
IPv6 Local Subnet
fe80:0000:0000:0000
```

```
IPv6 HostID
020d:3fff:fe01:1f9c
```

```
IPv6 Global Subnet
Network unavailable
```

MAC Address

```
MAC Address
00:0d:3f:01:1f:9c
```

LAN Reset

```
LAN Config Reset
Hold MENU to reset
```

Self-Test

```
Self Test
Hold MENU to start
```

The results of the self-test will show “Passed” or “Failed”. Use the web interface for detailed results of the last self-test.

```
Self Test
Passed
```

USB

```
USB at sda1
SP UFD U3
```

```
USB at sda1
Safe to remove
```

A USB device screen shows both the unique device name and the volume label. Holding the Menu button on a USB device screen will safely eject the device.

```
Data Logger: sda1
SP UFD U3
```

Each USB device also has a screen for use as a Data Logger. Holding the Menu button on this screen will cause the instrument to load a stored configuration file from the USB device and start a measurement. If the stored configuration file specifies, measured data may also be saved to the USB device during a Data Logger measurement. While a Data Logger measurement is in progress, a status screen will be displayed.

The status screen shows four items: Measurement State, Acquired Records, Completed Triggers, and Trigger Time Remaining.

- Measurement State: This indicates the current state of the measurement's trigger state machine. Possible values are:
  - Idle: Not running
  - Settle: Waiting for digital filters to settle
  - Start: Waiting for the configured Start event to occur
  - ArmWait: Waiting for the configured Arm event to occur
  - TrigWait: Waiting for the configured Trigger event to occur
  - PreTrig: Waiting for pre-trigger samples to be buffered
  - Meas: Measuring data after a trigger
- Acquired Records: The number of records measured so far this measurement.
- Completed Triggers: If Trigger Count is finite, the percentage of total triggers completed so far. If infinite, the number of triggers completed.
- Trigger Time Remaining: The amount of time remaining until the current trigger's data collection phase is complete. This is only displayed when Measurement State is Meas.

USB MEMORY DEVICES

The EX1401 provides a single USB 2.0 port on its rear panel. Any USB 2.0 or earlier compatible memory device can be attached. A USB hub may also be used to attach many USB memory devices at the same time.

Storage Devices APIs

The Instrument Driver includes a repeated capability exposing all attached USB memory devices at *Storage.Devices*. If any devices are attached or removed after initializing the instrument driver, the *Storage.Devices.Update* method will refresh the list. The *Enabled* parameter of each Storage Device item controls whether data will be saved to the storage device during measurement. The other properties allow querying information about the storage device and configuring the filename and other parameters about how data is saved.

All data stored to USB storage devices is written in HDF5 format, identical to that used by the Disk Streaming feature of the Instrument Driver. Files generated by either method can be read by the same software in the same way.

Stored Configurations

The EX1401 has the ability to store its configuration parameters as a JSON file on any attached USB memory device. This configuration file can then be loaded via the instrument driver at a later date, in order to restore the precise configuration at the time of saving. This configuration file is also used when a Data Logger measurement is performed via the instrument's rear-panel LCD display. Use the Instrument Driver's Configuration.SaveConfigurationToStorageDevice, Configuration.LoadConfigurationFromStorageDevice, Configuration.ClearConfigurationFromStorageDevice, and

Configuration.GetConfigurationDigestFromStorageDevice APIs to access the configuration file. Each of these APIs takes the Storage Devices repeated capability name as an argument.

Data Logging

The Storage Devices APIs and Stored Configurations features, along with the rear-panel LCD display, enable the EX1401 to act as a stand-alone Data Logger device.

To make use of stand-alone data logging with a USB memory device, the instrument should first be configured using the Soft Front Panel or Instrument Driver for the desired measurement parameters. This includes using the Storage.Devices APIs to enabling saving data to the USB device, if desired. The Configuration.SaveConfigurationToStorageDevice should then be called to save the desired measurement configuration to the USB device. The USB device can then be inserted into any EX1401 and used to perform the configured measurement via the rear-panel LCD display. For more information on using the LCD display for Data Logging, see the Operation of Data Logger, Chapter-6.

SECTION 4

WEB PAGE OPERATION

INTRODUCTION

The EX1401 instrument hosts an internal web page, which allows easy configuration, management and troubleshooting of the device. This internal Soft Front Panel (SFP) is a JavaScript based application which is designed to work, within web browser environment. If you know the IP address of the instrument, you can type it in the address bar of any modern web browsers, such as Microsoft Internet Explorer, Mozilla Firefox etc.

To open the embedded web page, simply type the IP address of the instrument into browsers address bar, and navigate accordingly. In order for your browser to communicate with the instrument, the instrument and your computer should be within the same network, and may require permissions from your network/computer administrator.

There are various ways to search the IP address, and other network configuration parameters of the instrument. The easiest method is to refer to the embedded display on the instrument, and use the menu key to navigate to necessary details. However, if the device display is not physically accessible, you can use LXI Discovery tool, or any standard IO Libraries tool, such as National Instruments (c) Measurement and Automation Explorer (MAX) and the Keysight (formerly Agilent) (c) Connection Expert (ACE) to discover the instrument. The instrument also supports mDNS protocols, so that any tools meant for Zero Configuration Networking, such as Apple ® Bonjour ®, Avahi. For more information on installation of these software utilities, please refer to their respective vendors.

The LXI Discovery tool is a free utility, available for download from LXI Consortium itself. It uses both VXI-11, as well as mDNS protocols to detect the LXI instruments present in your network. Once installed, this software will discover EX1401 instruments, if available, as shown below.

FIGURE 3-2: LXI DISCOVERY TOOL WITH EX1401 SELECTED

Alternatively, the EX1401 may also be discovered using Internet Explorer's Bonjour for Windows plug-in. The IP address of the EX1401 can also be entered into the address bar of any web browser to view the embedded web page. By default, the EX1401 will first attempt to use DHCP to set its IP Address. If DHCP is not available on the network it is connected to, it will instead use Auto IP. Determining the Auto IP address is discussed in the *Network Configuration* discussion in *Section 2*. Other discovery methods, such as VXI-11, can be used as well.

COMMON ISSUES

Although Ethernet is an easy connectivity option, some users may experience difficulty discovering LXI devices. Most often, these issues have been caused by networking issues, such as the instrument and host computer being connected to different sub-nets of the network. You may either search internet or contact your system / network administrator for assistance on these issues. Here are few other causes that may be present in your system which may obstruct instrument discovery:

Multiple Network Ports:

It may be possible that your computer, may have multiple network adaptors (physical / virtual). Common example of this case, is use of Wireless Internet / Wi-Fi in Laptop computers, whose Wired Ethernet connections are connected to LXI device connected network. In some cases, virtual network adaptors may have been created for use by some of your installed applications. The easy solution to these problems is to disable all other Ethernet connections and so force the computer to select the network port which is used by LXI Instrument.

Firewall

It is possible that your firewall of the computer may be stopping the data traffic to your LXI device. It may not be always feasible to stop the Firewall completely, and hence you may contact your computer administrator for making exceptions in Firewall configuration to allow LXI data traffic. Here are the list of ports and protocols, typically used by LXI devices.

Protocol / Service	Port	Base Protocol	Remarks

mDNS	5353	UDP/TCP	Zero-config protocol for <hostname>.local address resolution; service discovery; Multicast 224.0.0251, FF02::FB
HTTP	80	TCP	Instrument web pages (SFP) and driver communication
ICMPv4		ICMP	Typically enables echo request/respond for ping
ICMPv6		ICMP	Optional - Typically enables echo request/respond for ping, also SLAAC for IPv6 addresses, RDDNS
Arp		Arp	Used to confirm address assignments
DHCPv4	67/68	UDP/TCP	IPv4 address assignment, DNS Server, Dynamic DNS, Gateway
DNS	53	UDP	Naming service
SSH	22	TCP	Bidirectional interactive text oriented communication
RPC port-mapper	111	UDP/TCP	Builds upon Sun-RPC and port-mapper
VXI-11	Varies	TCP	VXI-11 instrument discovery The exact port number varies; query the RPC port-mapper to determine which port is current in use
LXI-eventsvc	5044	UDP/TCP	LXI Event support for instrument triggering; multicast 224.0.23.159, FF02::138. LXI Events can use other ports also, but default port number is 5044
Ptp-event	319	UDP/TCP	LXI Profile IEEE 1588 Precision Time Protocol (PTP); multicast 224.0.1.129, FF02::181
Ptp-general	320	UDP/TCP	LXI Profile IEEE 1588 Precision Time Protocol (PTP); multicast 224.0.1.129, FF02::181
Data stream	9900	TCP	Driver data stream

TABLE 3-8: STANDARD PORTS, PROTOCOLS, AND SERVICES

GENERAL WEB PAGE OPERATION

When initial connection is made to the EX1401, the instrument home page, or **Index**, appears. This page displays instrument-specific information. This page is accessible from any other instrument page by clicking on the EX1401 web page header. The EX1401 Navigation Menu is displayed on the left hand side of every internal web page. The entries on the Navigation Menu represent two types of pages:

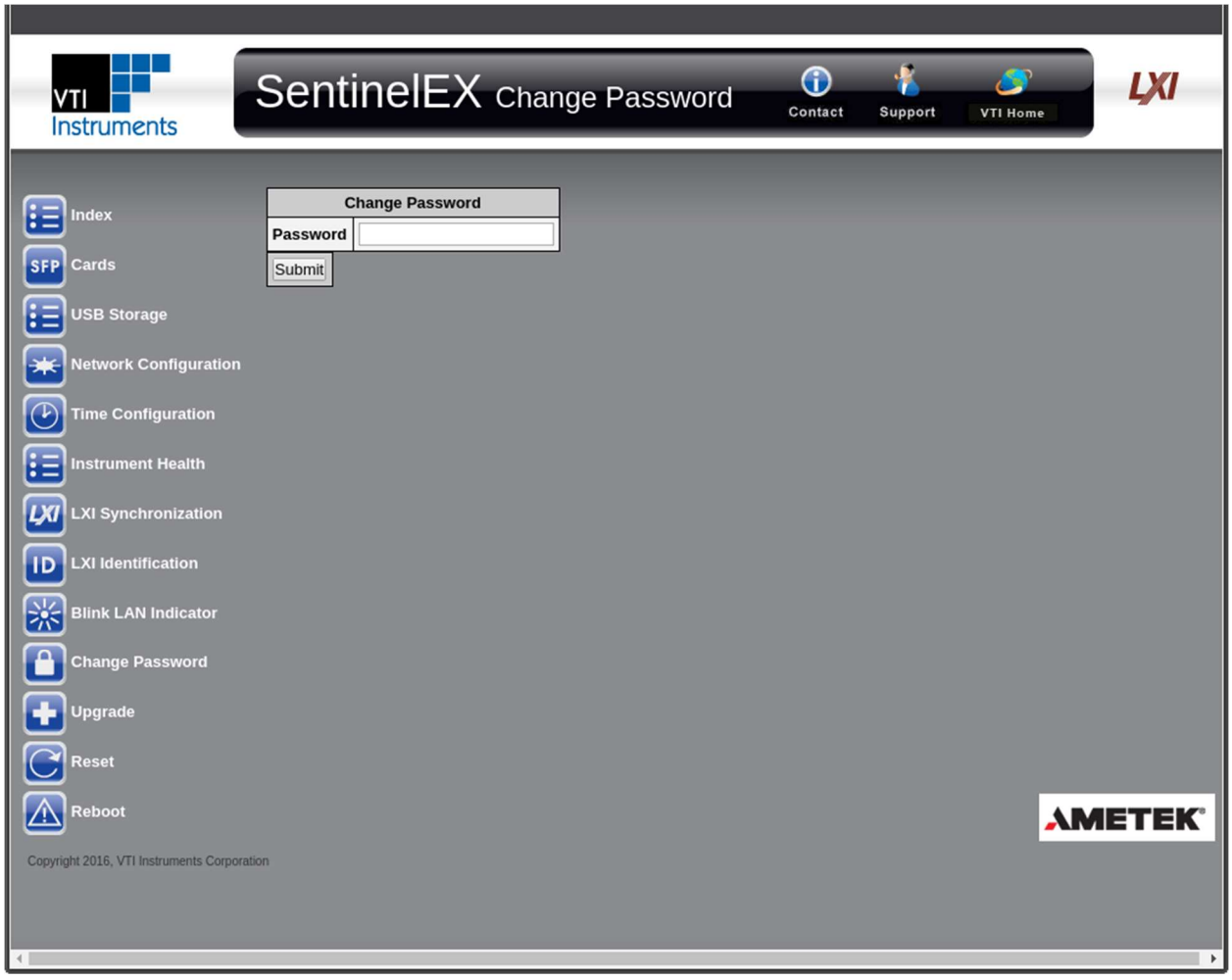
Status: These pages perform no actions and accept no entries. It provides operational status and information only. The Index page is an example of a status page.

Entry: These pages display and accept changes to the configuration of the instrument. The **Network Configuration** page is an example of an entry page. Use of the entry-type web pages in the EX1401 are governed by a common set of operational characteristics:

- Pages initially load with the currently-entered selections displayed.
- Each page contains a Submit button to accept newly entered changes. Leaving a page before submitting any changes has the effect of canceling the changes, leaving the instrument in its original state.
- Navigation through a parameter screen is done with the Tab key. The Enter key has the same function as clicking the Submit button and cannot be used for navigation.

LOGIN

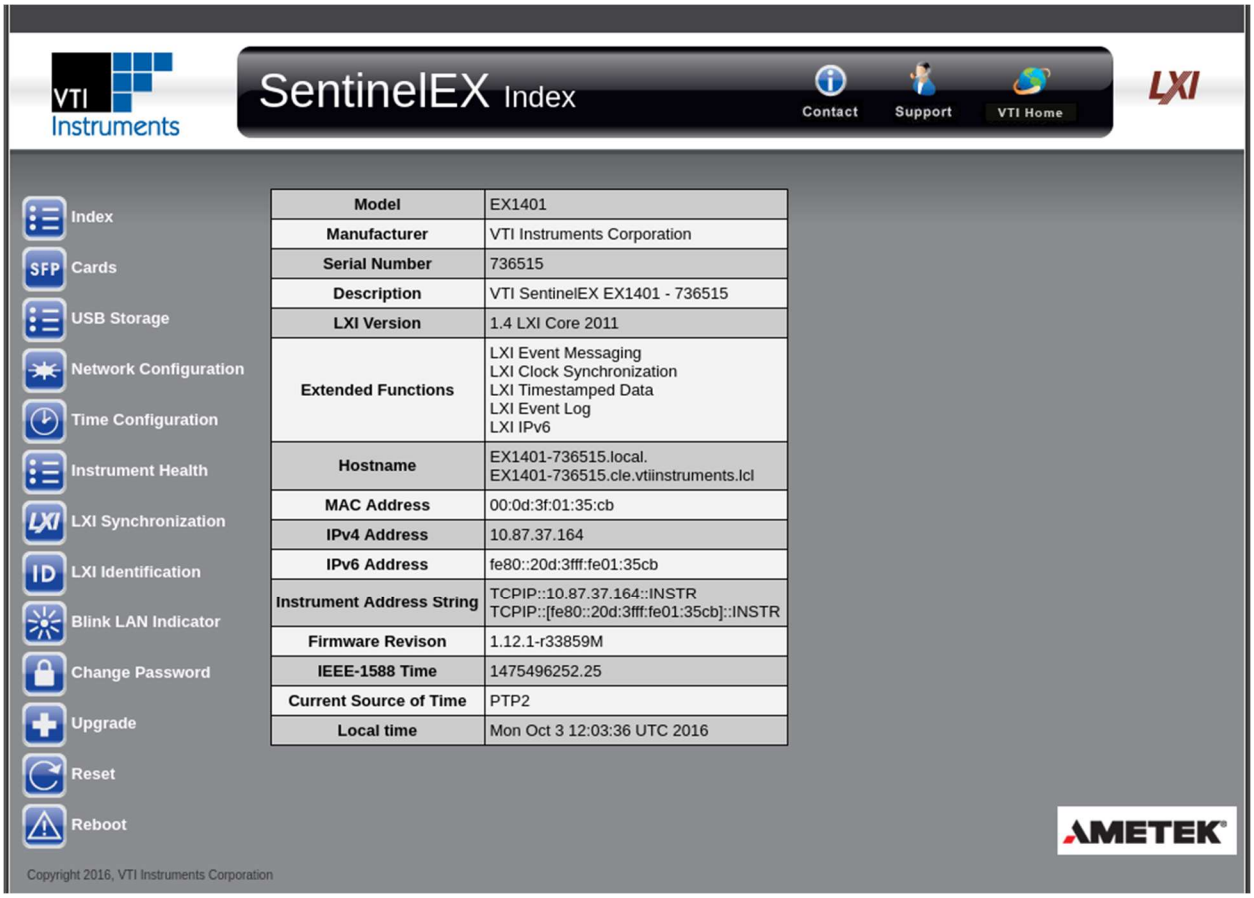
When accessing a page that allows changing configuration parameters of the EX1401, a password may be required. If so, the Login page will appear.



To log in, simply enter the password in the given text field, and press the Submit button. By default, the EX1401 has no password. To change the password, visit the Change Password page. If the password is unknown, performing a network reset operation will reset the EX1401 to no password.

INDEX

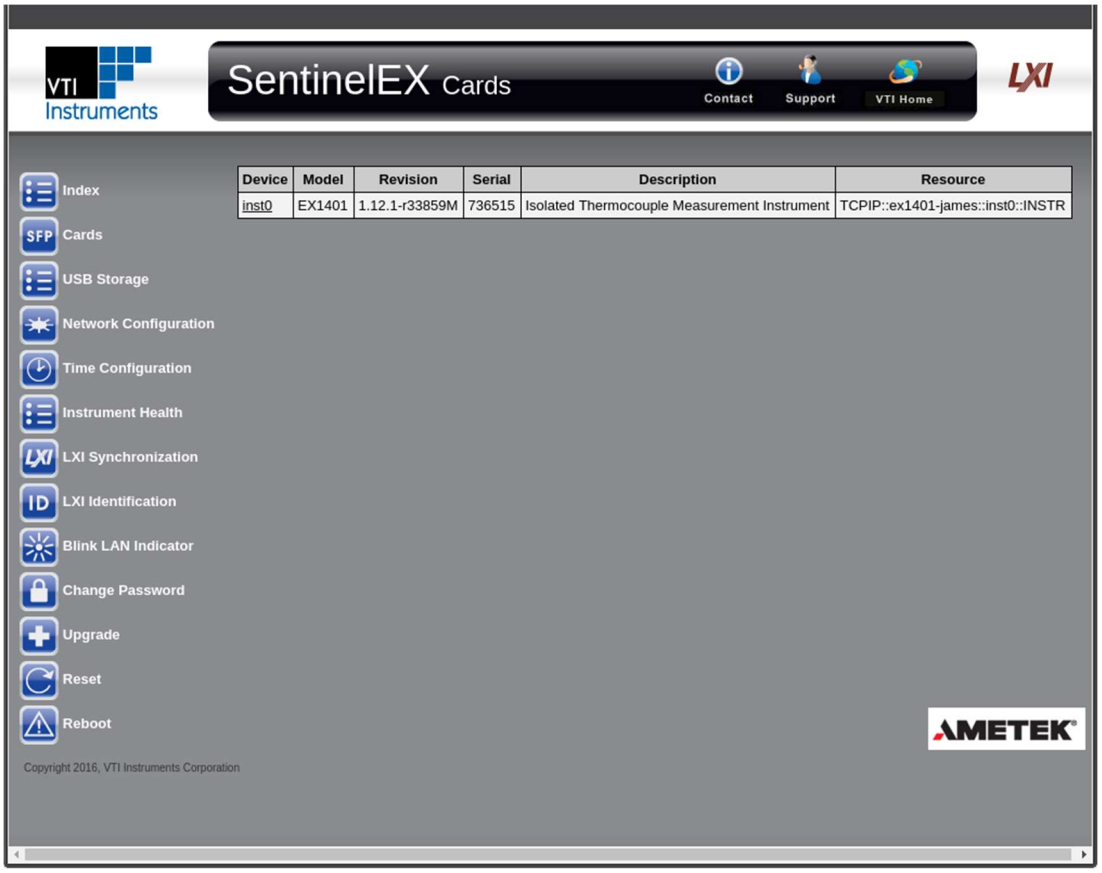
The Index page provides the general information about the EX1401.



- Model: The model number of the module.
- Manufacturer: The module manufacturer.
- Serial Number: The module's serial number.
- Description: A brief, user-configurable description of the module.
- LXI Version: Indicates which version of the LXI specification the module conforms to.
- Extended Functions: Indicates which LXI Extended functions are supported.
- Hostname: Indicates the Full Qualified Domain Names of the module. The first part of each FQDN is the user-configured hostname.
- MAC Address: Indicates the factory-assigned MAC address of the module.
- IPv4 Address: Indicate the current IPv4 address of the module.
- IPv6 Address: Indicates the current IPv6 address(es) of the module.
- Instrument Address String: Indicates the resource string(s) by which the module can be accessed via its instrument driver.
- Firmware Revision: Indicates the current revision of the module's firmware.
- IEEE-1588 Time: The current IEEE-1588 time.
- Current source of time: Indicates from which source the module is deriving its time.
- Local time: The module's current time, as expressed in the currently configured time zone.

CARDS

The Cards page lists all modules of the EX1401. Because the EX1401 is not a modular instrument, this consists solely of one module: inst0.

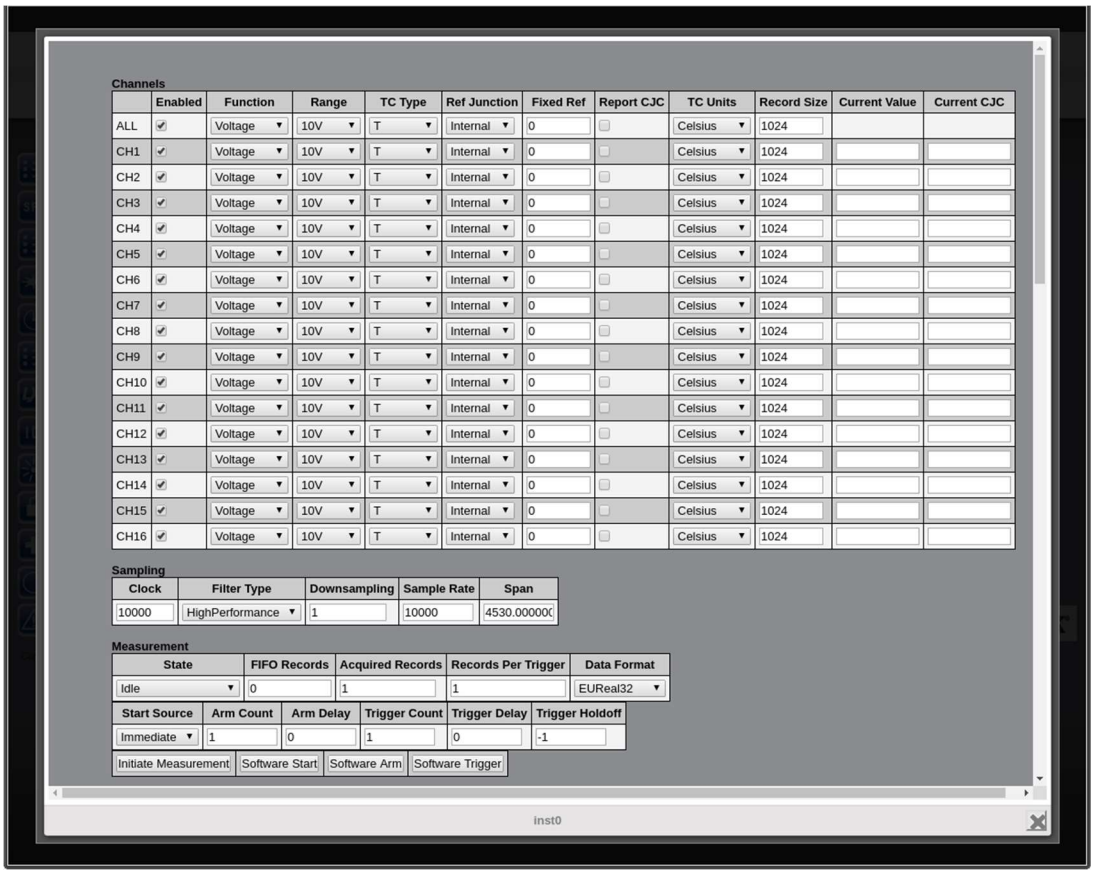


The following information is provided for each module:

- **Device**: The bus and slot number of the module. Clicking on the name will launch the instrument control Soft Front Panel.
- **Model**: The model number of the module.
- **Revision**: The firmware version of the module.
- **Serial**: The serial number of the module.
- **Description**: A brief description of the module.
- **Resource**: A resource string that can be used to access the module via its instrument driver.

SOFT FRONT PANEL

The Soft Front Panel popup allows configuration and control of the instrument. It includes access to all firmware APIs exposed by the instrument driver and presents them via an AJAX-enabled web page.



The majority of the Soft Front Panel's fields correspond 1-to-1 with the APIs of the Instrument Driver. Refer to the Programming section for basic information on how to configure the instrument, which is all applicable to the SFP as well.

Changing the value in most of the text entry, drop-down menu, and check box controls of the SFP will cause your browser to send an HTTP PUT request to the instrument, changing the appropriate setting. The browser will then immediately send a GET request for the same property, and update the contents of the field with the result. This allows the SFP to keep up to date when the firmware coerces or rejects a value. Some settings can also affect the value of other properties. When this happens, the response to the HTTP PUT will include a cache invalidation header for those properties, prompting the SFP to submit HTTP GET requests for those fields as well.

Some fields in the SFP (such as Overload Status, FIFO Records, and Time) are read-only. These can be polled for updates by clicking on them. The firmware will submit a GET request for any read-only field whenever it is clicked.

To begin a measurement in the SFP, click the "Initiate Measurement" button in the Measurement section. While the measurement is running, the State, FIFO Records, and Acquired Records fields will be updated up to 4 times per second, showing the state of the measurement. The "Current Value" field of the Channels table (as well as "Current CJC" if "Report CJC" is checked) will also be updated with the latest measured value from each enabled channel while the measurement is

running. If the DIO setting "Reporting Enabled" is checked, then the current input state of the DIO port will also be updated during measurement in the "7" through "0" fields. Note that the data shown under "Current Value" is not necessarily part of a record – it is simply the newest data in the instrument's circular buffer FIFO.

Any records in the instrument FIFO can be downloaded by clicking the "Download CSV" button in the Measurement section. The "Download Records" field indicates how many records will be removed from the FIFO and converted to CSV format for download. Checking the "All" box causes the SFP to download all available records instead.

Measured data can also be plotted in the *Data Plot* section of the SFP. The following options are available:

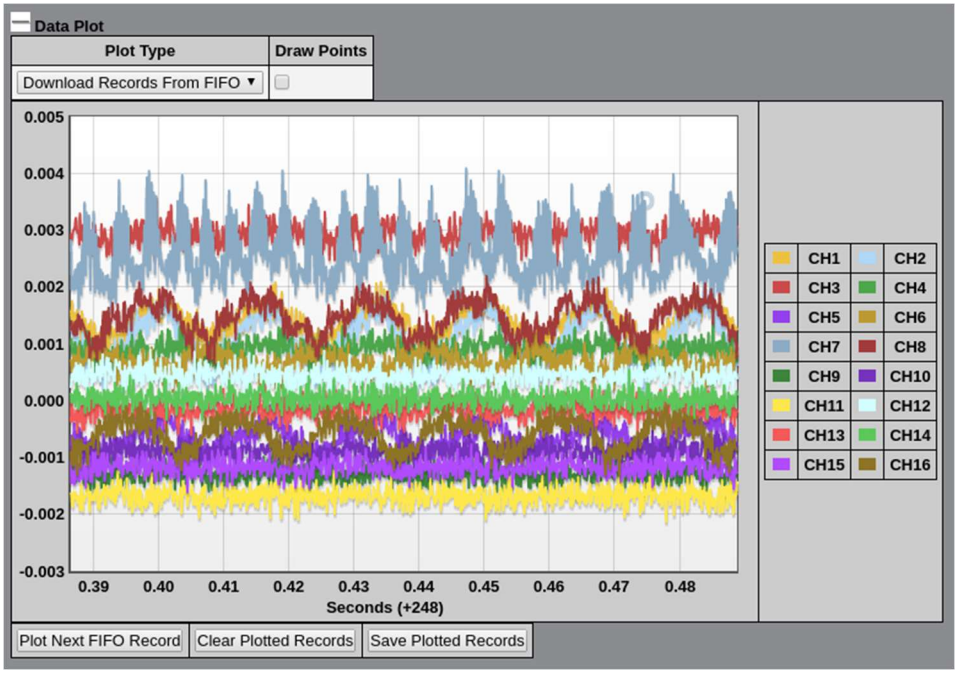
- **Plot Type** controls the plot's mode of operation and has two options:
  - **Poll Current Value Table** will plot each new data point that is polled from the Current Value Table in real time, whenever a measurement is running. When this mode is selected, the following parameters are available:
    - **CVT Polling Frequency (ms)** controls the amount of time waited between pollings of the instrument's measurement state and Current Value Table. Valid values are from 100 to 10000 ms.
    - **Maximum CVT Points** is the maximum number of Current Value Table points to plot at one time. After this many points is reached, the oldest will be removed from the plot whenever a new one is added. Valid values are from 8 to 512.
  - **Download Records From FIFO** allows records to be downloaded from the instrument's FIFO and plotted directly in the SFP. When this mode is selected, the following buttons are available:
    - **Plot Next FIFO Record** pops a record from the FIFO, downloads it, and adds it to the current plot.
    - **Clear Plotted Records** removes all currently plotted records. Because all data is plotted on a common time-axis, adding data that was acquired far apart in time can create a large gap in the plot. It is recommended to clear the plot before adding more data if the next record is not close in time to the already plotted data.
    - **Save Plotted Records** downloads all currently plotted data in CSV format.
  - **Draw Points** controls whether a marker is drawn on each plotted data point, in addition to the line. Turning this on is helpful with small data sets, but with large amounts of data, it can slow down plotting significantly, as well making the plot itself less readable.

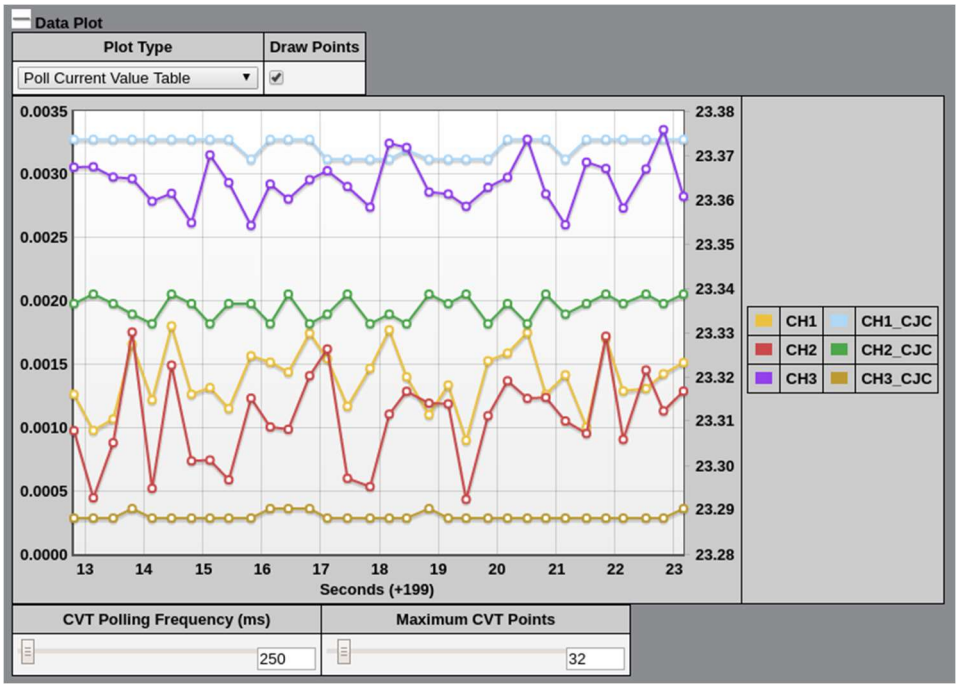
All channel data is plotted via a shared Y-axis, in the selected units for each channel, even if not all channels are configured to use the same units. If *Report CJC* is enabled for any channels, the CJC data is plotted on a separate Y-axis, which is placed to the right of the plot area.

The plot's X-axis is always the time axis, in units of seconds. The values on the axis will always be offset by the seconds portion of the first plotted point's time value after clearing the plot (FIFO mode) or starting a new measurement (CVT mode). The offset value will be displayed next to the X-axis label. For instance, if the timestamp of the first plotted value is 34.567, the X-axis label will read "Seconds (+34)" and the first plotted value will appear at 0.567 seconds on the plot. This allows large IEEE 1588 time values to be plotted without crowding the X-axis tick labels.

Hovering the mouse pointer over any plotted point will pop up a message identifying the channel name, as well as both the X- and Y-axis values for the point. X-axis values in this message are the full offset-corrected values.

DIO data cannot be plotted via the SFP. But, if the DIO Reporting Enabled property is True, any DIO records associated with plotted channel data records will be included in CSV data that is downloaded via the *Save Plotted Records* button.





USB STORAGE

The USB Storage page lists all USB storage devices connected to the instrument.

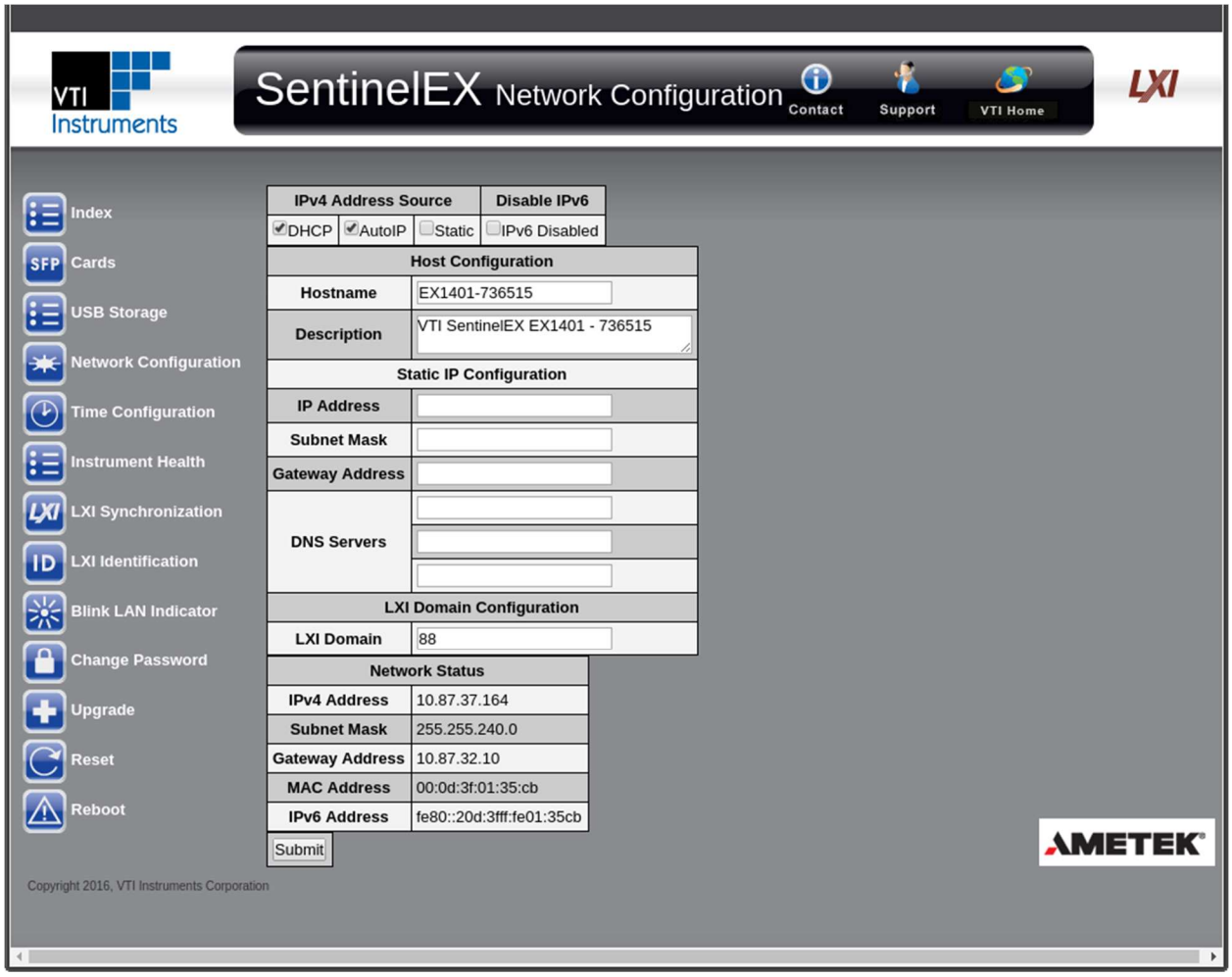
The following information is provided for each USB Storage device:

- **Device Name**: The unique name of the storage device.
- **Label**: The volume label.
- **Size**: The total amount of storage space available.
- **Used**: The amount of space used.
- **Use %**: The percentage of total space used.

Each device also includes an **Eject** link. Clicking this will cause the instrument to disconnect the storage device so that it can be safely removed.

NETWORK CONFIGURATION

The Network Configuration Page contains information concerning the configuration of the EX1401's network interfaces, and provides the ability to modify it.

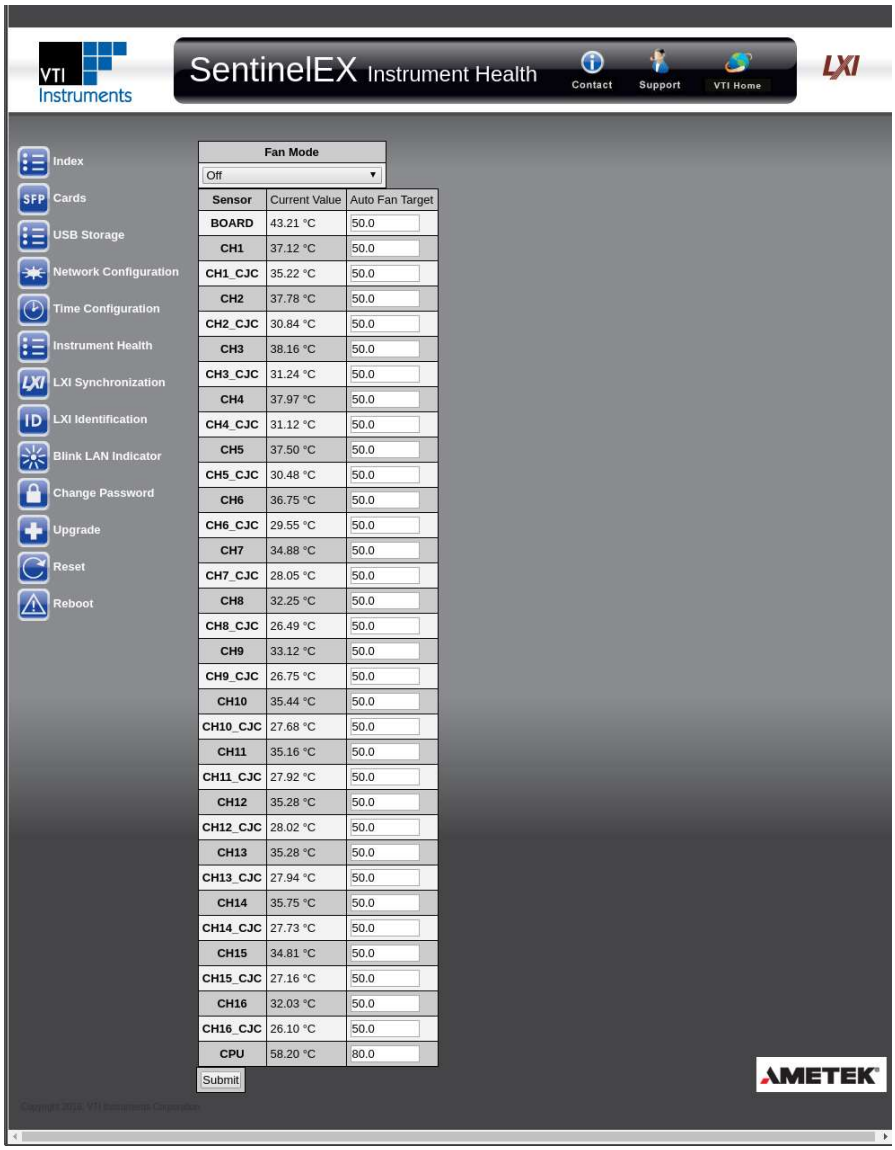


- **IPv4 Address Source**: The IPv4 address for the EX1401 is determined by one of three sequenced mechanisms: **DHCP → AutoIP → Static**. If an IP address cannot be obtained with the first mechanism, it will progress to the next method. The user also has the ability to enable or disable either of these methods by utilizing the adjacent checkboxes.
    - **DHCP**: A protocol that obtains an IP address automatically if the EX1401 is connected to a network with a DHCP server. By default, the EX1401 will attempt to locate a DHCP server. If one is found, the IP address assigned by the DHCP server will be assumed. Otherwise, after a timeout of 20 seconds, the unit will attempt to obtain an IP address by using AutoIP.
    - **AutoIP**: A protocol that automatically creates a link-local IP address based on theEX1401's MAC address. If the IP address created is not available on a network, another IP will be chosen randomly.
    - **Static**: A user-configured IP address which remains constant. Both DHCP and AutoIP generated IP addresses may change after a reset condition.
- **Disable IPv6**: When checked, IPv6 addressing will be disabled, and the EX1401 will only be accessible via IPv4.

- **Hostname**: Indicates a name which other devices may use to communicate with the EX1401 instead of using its IP address. When mDNS service discovery is used, the host name for the unit will appear. The default hostname is "EX1401-[serial number]". To reset the hostname to the factory default, delete the current value and submit the page with nothing in this field.
- **Device Description**: This user-configurable field can be used to provide additional information regarding the module (i.e. location, use, etc.). This is visible on the **Index** page without the need for a password. If set, this description will be used as the Service Name for mDNS service discover instead of the hostname above. To reset the description to the factory default, delete the current value and submit the page with nothing in this field.
- **Static IP Configuration**: This configuration section is used to create a Static IP address.
    - **IP Address**: The user-configured IP address is entered into this text field.
    - **Subnet Mask**: Defines the range of IP addresses the EX1401 will attempt to connect to directly (255.255.255.0 means match all but the last number, etc.).
    - **Gateway Address**: The IP address of a server that EX1401 can use to contact IP addresses external to its network.
    - **DNS Servers**: This field is used to provide the IP Addresses of servers that the EX1401 module may use to look up hostnames (e.g. www.vtiinstruments.com).
- **Network Status:** Indicates the current network settings for the EX1401's IPv4 Address, Subnet Mask, Gateway Address, MAC Address, and IPv6 Address.

INSTRUMENT HEALTH

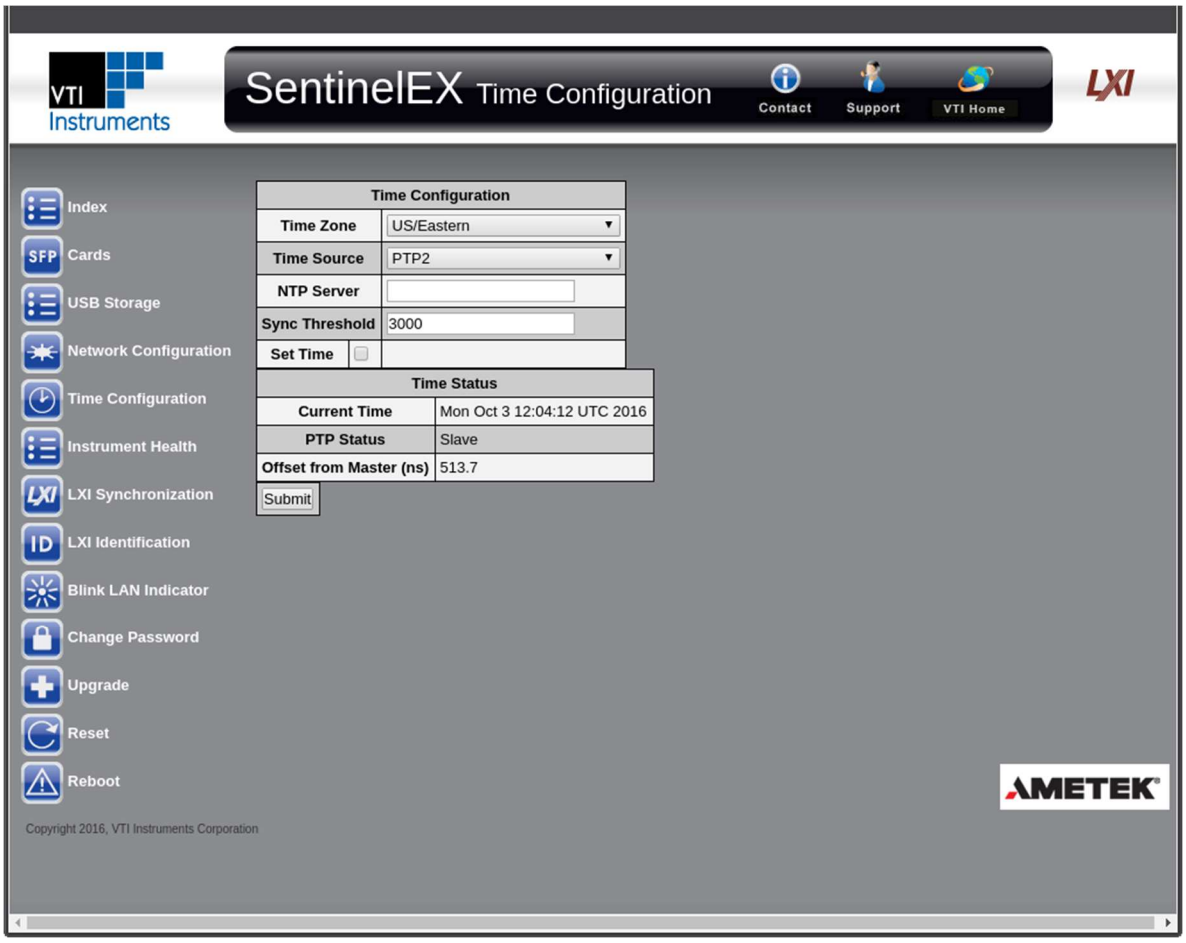
The Instrument Health Page contains information concerning the EX1401's temperate sensors and fan controls.



- Fan Mode:
  - **Off**: The fan will remain off at all times.
  - **On**: The fan will run at all times.
  - **Auto**: The fan will turn on whenever any of the temperature sensors' Current Value is above its **Auto Fan Target**.
- **Temperature Sensors**: This table lists all of the available temperature sensors in the instrument, along with their **Current Value** and **Auto Fan Target**.
  - **BOARD**: This temperature sensor is located in the digital section near the rear of the instrument, directly attached to the main circuit board.
  - **CPU**: This is the embedded temperature sensor in the CPU die.
  - **CH1-16**: These temperature sensors are embedded in the low-speed auxiliary ADC of each channel. They are accurate to…
  - **CH1-16_CJC**: These are the actual Cold Junction Compensation sensors.

TIME CONFIGURATION

The Time Configuration Page contains information concerning the configuration of the EX1401's source of time, and provides the ability to modify it.

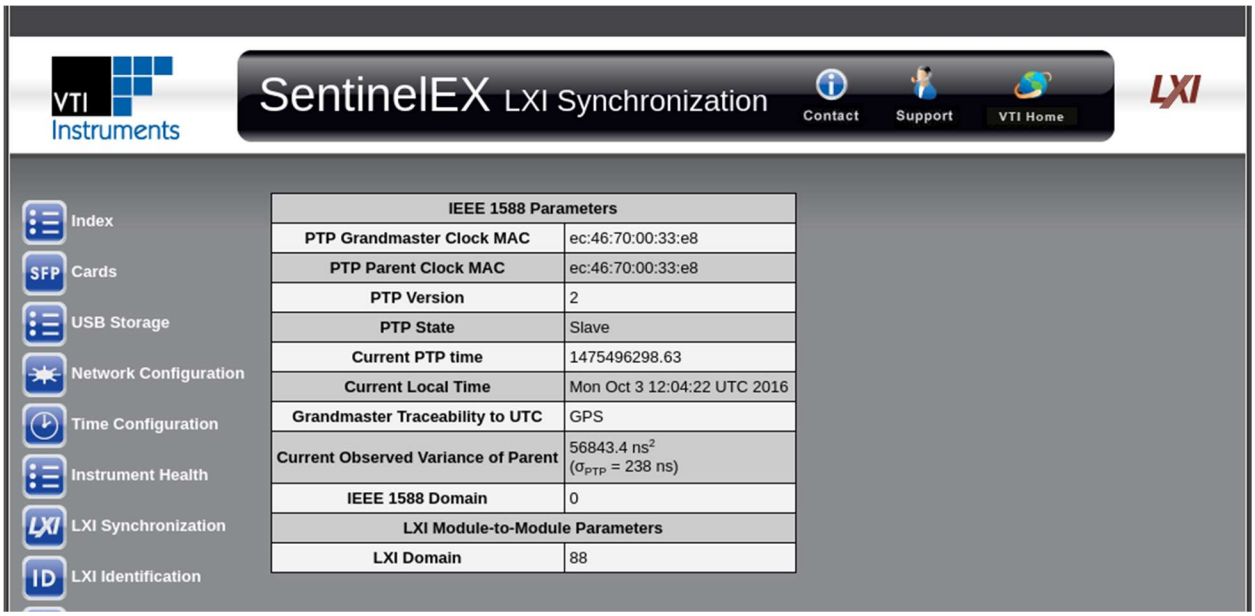


- **Time Configuration**:
  - **Time Zone**: Allows the user to select the time zone for displaying the current local time.
  - **Time Source**: Selects the method to use for setting the EX1401's time.
    - **PTP2**: Precision Time Protocol Version 2 (IEEE 1588-2008) will be used to synchronize the EX1401's time with a master clock on the network, or to act as master clock, based on the IEEE 1588 Best Master Clock algorithm.
    - **NTP**: Network Time Protocol will be used to synchronize the EX1401's time to a remote server, which is specified in the **NTP Server** field below.
    - **Manual**: The time will be set manually by the user via the **Set Time** option below.
  - **NTP Server**: The IP Address or hostname of the server from which to derive time when the **NTP** option is selected. If this is left blank, one of the following values will be used by instead:
    - If the EX1401 is configured for DHCP, and if the DHCP server supplies the address of an NTP server, that will be used.
    - Otherwise, the default value of pool.ntp.org will be used.
  - **Set Time**: Checking the **Set Time** box causes the **Date** and **Time** fields to appear. They will be automatically populated with the current time of the user's PC. When using the **Manual** option, this sets the EX1401's current date and time. When using the **PTP2** option, this causes a message to be sent to the current master clock, requesting that it set its time.

- **Time Status**:
  - **Current Time**: The current date and time of the EX1401, translated to the UTC time-base and the selected time zone.
  - **PTP Status**: The current state of the **PTP2** protocol within the EX1401.
  - **Offset from Master (ns)**: An estimate of the current error, in nanoseconds, of the EX1401's time from that of its PTP master.

LXI SYNCHRONIZATION

The LXI Synchronization page provides status on the EX1401's synchronization status.



IEEE 1588 Parameters	
PTP Grandmaster Clock MAC	ec:46:70:00:33:e8
PTP Parent Clock MAC	ec:46:70:00:33:e8
PTP Version	2
PTP State	Slave
Current PTP time	1475496298.63
Current Local Time	Mon Oct 3 12:04:22 UTC 2016
Grandmaster Traceability to UTC	GPS
Current Observed Variance of Parent	56843.4 ns^2 (σ_{PTP} = 238 ns)
IEEE 1588 Domain	0
LXI Module-to-Module Parameters	
LXI Domain	88

- **IEEE 1588 Parameters**
  - **PTP Grandmaster Clock MAC**: The MAC address of the device on the network to which all other IEEE 1588 compliant devices are synchronized.
  - **PTP Parent Clock MAC**: The MAC address of the device to which the EX1401 is synchronized. In a hierarchical IEEE 1588 system with boundary clocks, this indicates the MAC address of the parent clock on the local link.
  - **PTP State**: Indicates whether the EX1401 is initializing, faulty, disabled, listening, pre-master, master, passive, uncalibrated, or slave.
  - **Current PTP Time**: The current time on the EX1401, expressed as the number of seconds since midnight January 1, 1970 TAI.
  - **Current Local Time**: The current date and time of the EX1401, translated to the UTC time-base and the selected time zone.
  - **Grandmaster Traceability to UTC**: Indicates how the grandmaster is synchronized to UTC. The values provide an indicator of how closely synchronized the grandmaster is to UTC time.
  - **Current Observed Variance of Parent**: This function is not supported by the EX1401.
  - **IEEE 1588 Domain**: The instrument's PTP domain. Typically, this indicator is 0.
    - LXI Module to Module Parameters
  - **LXI** Domain: An 8-bit number, 0 to 255, which indicates the domain the EX1401 is using for LAN Events. All events sent by this device will include this number. Likewise, the device will only accept events that include the same LXI Domain number.

LXI IDENTIFICATION

The LXI Identification page is a XML document providing identifying information on the EX1401.

Manufacturer	VTI Instruments Corporation
Model	EX1401
SerialNumber	736515
FirmwareRevision	1.12.1-r33859M
ManufacturerDescription	Isolated Thermocouple Measurement Instrument
HomepageURL	http://www.vtiinstruments.com
DriverURL	http://www.vtiinstruments.com/GeneralSearch.aspx?keyword=EX1401
UserDescription	VTI SentinelEX EX1401 - 736515
IdentificationURL	http://ex1401-james/lxi/identification
InstrumentAddressString	TCPIP::EX1401-736515.cle.vtiinstruments.lcl::INSTR
Hostname	EX1401-736515.cle.vtiinstruments.lcl
IPAddress	10.87.37.164
SubnetMask	255.255.240.0
MACAddress	00:0d:3f:01:35:cb
Gateway	10.87.32.10
DHCPEnabled	true
AutoIPEnabled	true
InstrumentAddressString	TCPIP::[fe80::20d:3fff:fe01:35cb]::INSTR
Hostname	EX1401-736515.cle.vtiinstruments.lcl
IPAddress	fe80::20d:3fff:fe01:35cb
SubnetMask	64
MACAddress	00:0d:3f:01:35:cb
Gateway	
DHCPEnabled	false
AutoIPEnabled	false
IVISoftwareModuleName	VTEXPlatform "VTI Platform Driver"
Domain	88
LXIVersion	1.4 LXI Core 2011
Function	"LXI Event Messaging" "1.0"
Function	"LXI Clock Synchronization" "1.0"
Function	"LXI Timestamped Data" "1.0"
Function	"LXI Event Log" "1.0"
Function	"LXI IPv6" "1.0"

- **Manufacturer**: The module manufacturer.
- **Model**: The model number of the module.
- **SerialNumber**: The module's serial number.
- **FirmwareRevision**: Indicates the current revision of the module's firmware.
- **ManufacturerDescription**: A brief description of the module.
- **HomepageURL**: The address of the manufacturer home page.
- **UserDescription**: The user-configurable description field.
- **IdentificationURL**: The canonical URL of this document.

- **Network Interface Information**: The following fields will be repeated once for each network interface present in the module:
  - **InstrumentAddressString**: Indicates the resource string by which the module can be accessed via its instrument driver.
  - **Hostname**: Indicates the Full Qualified Domain Name of the module. The first part of the FQDN is the user-configured hostname.
  - **IP Address**: Indicate the current IP address of the module.
  - **SubnetMask**: Indicates the range of IP addresses the EX1401 will attempt to connect to directly.
  - **MAC Address**: Indicates the factory-assigned MAC address of the module.
  - **Gateway**: The IP address of a server that EX1401 can use to contact IP addresses external to its network.
  - **DHCPEnabled**: Indicates whether DHCP is enabled on the interface.
  - **AutoIPEnabled**: Indicates whether AutoIP is enabled on the interface.
- **IVISoftwareModuleName**: Indicates the name and description of an IVI-compliant instrument driver that can be used to control the instrument.
- **Domain**: The LXI LAN Event Domain number, 0-255.
- **LXIVersion**: Indicates which version of the LXI specification the module conforms to.
- **Function**: Indicates an LXI Extended Function, and its version, that is supported by the module.

BLINK LAN INDICATOR

The Blink LAN Indicator page allows identification of the device being accessed by causing its LAN LED to blink. This is helpful when there are multiple instruments present in your system and you need to identify a specific device by its IP address.

- **Turn On**: Cause the EX1401's LAN LED to blink.
- **Turn Off**: Cause the EX1401's LAN LED to stop blinking.

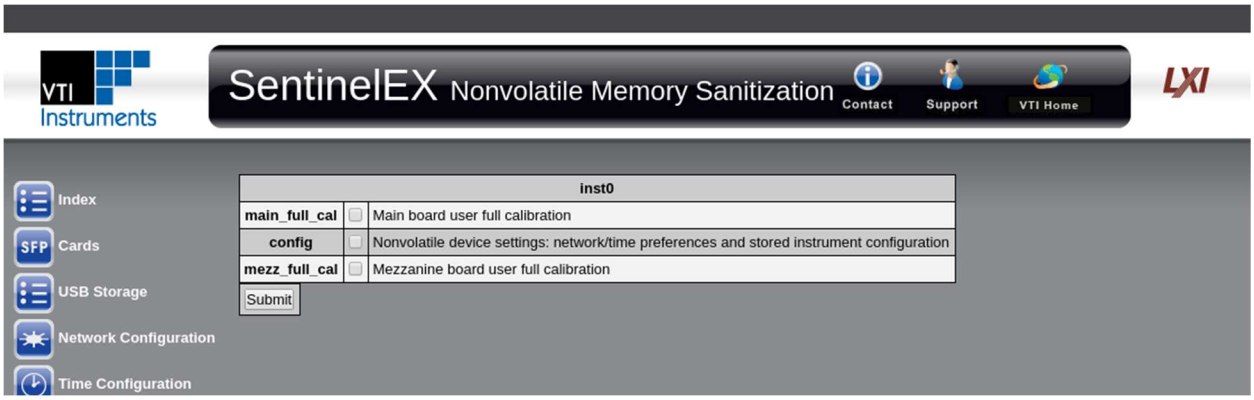
CHANGE PASSWORD

The Change Password page allows the password to be updated.

- **Password**: Set a new password to control access to configuring the EX1401. Setting an empty password disables password requirements.

NONVOLATILE MEMORY

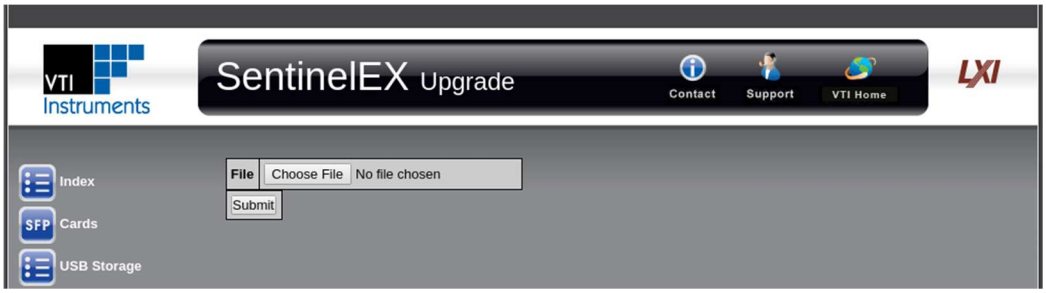
The Nonvolatile Memory web page provides the ability to securely erase the contents of the EX1401's user-writable memory devices.



- **config**: Securely erases the instrument configuration partition of the main instrument flash. This includes all settings that can be configured through the instrument web page and any stored instrument configurations saved via the instrument driver of Soft Front Panel.
- **main_full_cal**: Securely erases the user full calibration portion of the main board's calibration and identification EEPROM. This contains all of the user-supplied calibration information for CH1-8. The factory-supplied full calibration will not be affected.
- **mezz_full_cal**: Securely erases the user full calibration portion of the mezzanine board's calibration and identification EEPROM. This contains all of the user-supplied calibration information for CH9-16. The factory-supplied full calibration will not be affected.

UPGRADE

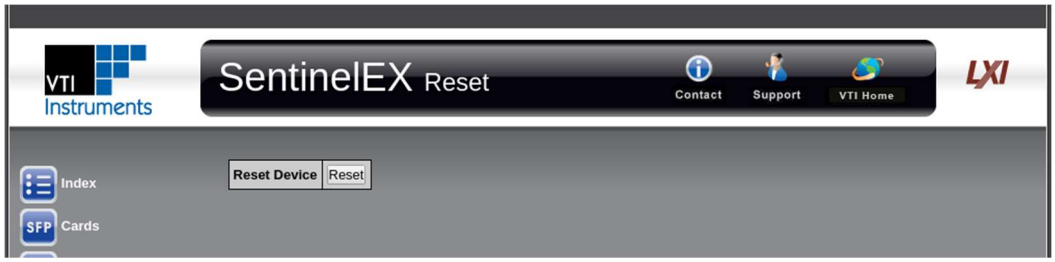
The Upgrade web page provides the ability to upgrade the firmware of the EX1401. Upgrade files are available from the *VTI Instruments User's Manuals and Drivers CD*, or from the VTI Instruments web site, at http://www.vtiinstruments.com/Downloads.aspx.



- **File**: Choose an upgrade file.

RESET

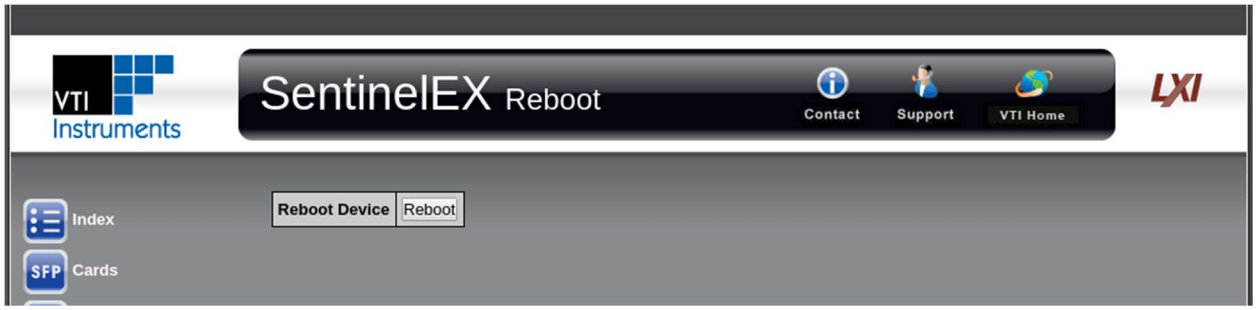
The Reset web page allows the EX1401 to be returned to power-on default settings. This operation is faster than a reboot, but does not load new firmware.



- **Reset**: Click this button to reset the EX1401 to power-on defaults.

REBOOT

The Reboot web page allows the EX1401 to reboot. This operation has the same effect as power-cycling the unit – it will re-load firmware from nonvolatile memory and return to power-on defaults.



- **Reboot Device**: Click this button to reboot the EX1401.

SECTION 5

INSTRUMENT DRIVERS

OVERVIEW

Three drivers, VTEXDigitizer, VTEXDsa, and VTEXPlatform (or libDigitizer, libDsa, and libPlatform, respectively, for Linux), are used to program the EX1401 instruments. The "Digitizer" drivers are common drivers used by all EX Series and EMX Series digitizer devices provided by VTI Instruments. For a simple data acquisition application, the "Digitizer" driver may be the only driver the user needs to use. The "DSA" driver is essentially a super set of the "Digitizer" driver. In addition to the data acquisition functionalities in the "Digitizer" driver, the "DSA" driver also supports the EMX-1434's signal output and tachometer input capabilities. The "Platform" driver is used to configure the EX1401's LXI device specific features, as per IVILXISync API guidelines.

IVI DRIVERS

The IVI Foundation defines IVI driver specifications. IVI specification information is available at the IVI Foundation website, www.ivifoundation.org. The IVI-3.2 Inherent Capability Specification defines a common set of basic functionality that all IVI driver must support. This ensures that users can perform basic operations and identify its capability for any IVI driver using the exact same API functions. The IVI drivers are implemented using a common code provided by the IVI Foundation in order to guarantee this consistent behavior. This common code is called the IVI Shared Components. The IVI Shared Components must be installed separately prior to any IVI drivers from VTI. The shared components installer is available for download from the IVI Foundation website.

The IVI Foundation specifies that the IVI driver be based on Microsoft Component Object Model, called IVI-COM and an IVI driver using standard C language API, called IVI-C. For those who develop applications in Windows .NET languages, such as C#, VB.NET, or other Object Oriented Language, such as C++, IVI-COM gives APIs logically organized by interfaces. IVI-C gives more traditional C language functions.

While VTI's IVI drivers are architected based on IVI-COM, the driver installer also installs a wrapper library that exposes IVI-C functions so that the user can use develop in both types of environment.

Header and Library Files

The IVI driver specification defines the install directory structure and software components to be installed. For 32-bit Windows systems, the root of install directory is `C:\Program Files\IVI Foundation\IVI`. For 64-bit Windows systems, the 32-bit driver is installed at `C:\Program Files (x86)\IVI Foundation\IVI` and the 64-bit driver is installed at `C:\Program Files\IVI Foundation\IVI`. Driver header files and library files are installed in several sub directories. The **Bin** subdirectory contains IVI-COM and IVI-C driver DLL files. The **Component** subdirectory contains IVI-COM and IVI-C shared components files. The **Drivers** subdirectory contains the driver specific sub directories. The driver's online help files and example programs are installed here. The **Include** subdirectory contains header files. The **Lib** subdirectory contains 32-bit import library files. The **Lib_x64** subdirectory contains 64-bit import library files.

DRIVERS FOR LINUX OS

In addition to the IVI drivers for Windows OS, C++ libraries are provided for the Linux operating system. The Linux drivers are supported on distributions running Linux kernel version 2.6.32 or later. In addition, the Linux drivers require GCC version 4.4 or later and glibc 2.12 or later. The driver for Linux organizes and names each C++ class and members consistent to the IVI-COM driver. The driver description in this manual applies to both IVI driver and the library for Linux OS.

The Linux drivers are supplied as RPM packages which are supported by a wide variety of distributions. In distributions which natively support RPM packages, such as Red Hat Enterprise Linux, Fedora Linux, or CentOS, the driver packages can be installed by running the command:

```
rpm –Uvh packagename.rpm
```

There are many other popular Linux distributions which do not natively support RPM packages, but instead use third-party tools to install them. Debian and Ubuntu Linux are both very popular, but do not support RPM packages out of the box. To use these packages on these systems, 'alien' is recommended which should be available in the package repository for these distributions. To install the drivers using alien, run the command:

```
alien –i packagename.rpm
```

Currently, there are both 32- and 64-bit driver packages for libDigitizer, and libPlatform. There is also a package which installs common libraries and dependencies used by all drivers, libCommon. The appropriate libCommon package (32-bit or 64-bit) must be installed before installing any of the other driver packages. The release notes for the libCommon package include information on the exact compiler version used for a particular release.

Header and Library Files

`/opt/vti/include` sub directory contains header files.

`/opt/vti/lib` sub directory contains driver shared object files.

`/opt/vti/share/doc` sub directory contains release notes, driver online help and example programs

BUILDING AND RUNNING EXAMPLE PROGRAMS

Windows Examples

The instrument drivers come with example programs that the user can build and execute. Example programs are in C++ and C# (Windows only) programming language. They are installed in the *Examples* sub-folder under the standard IVI driver installation folder, which is usually found at *C:\Program Files (x86)\IVI Foundation\IVI\Drivers\VTEXDigitizer\Examples* or *C:\Program Files\IVI Foundation\IVI\Drivers\VTEXDigitizer\Examples*. A link to the example programs can also be found in the Start Menu.

Linux Examples

Linux examples are stored at */opt/vti/share/doc/digitizer/examples/*. To build them, copy that folder to a writable location, change directory to the examples folder and run *make*.

```
~$ cd /tmp

/tmp$ cp -r /opt/vti/share/doc/digitizer/examples/ .

/tmp$ cd examples/

/tmp/examples$ make

g++    -o    Initialization    Initialization.cpp    -
I/opt/vti/include -

L/opt/vti/lib -Wl,-rpath=/opt/vti/lib -lDigitizer

/tmp/examples$ ./Initialization 10.20.10.158
```

COMPATIBILITY

DRIVER AND FIRMWARE REVISIONS

The instrument driver and firmware have three revision fields: <Major>, <Minor>, and <Build>. For the firmware installed on the instrument to be compatible with the driver being used, the <Major> version number must be equal and the <Minor> version must be equal or newer than the driver. Otherwise, the firmware needs to be updated. It is recommended to use the same <Major> and <Minor> version pair, if possible.

DRIVER API AND INSTRUMENTS

The Digitizer driver is designed to work with many digitizer products from VTI Instruments. Not all API functions defined in the driver apply to every digitizer product, since each model has a unique feature set. Calling unsupported API functions will result in a property not supported or method not supported error. See the manuals for the other digitizer products for more details on their supported features.

Digitizer APIs	EX1401 Support	EMX-4250/4350/4380
Alarms	Supported	Not Supported
Arm	Supported RPM (DSA), Pattern (DSA) not supported by digitizer devices	Supported RPM (DSA), Pattern (DSA) not supported by digitizer devices
Calibration	Supported Self-calibration not supported	Supported
Channels	Supported, including Temperature and Transducer AutoCal, AutoRange, Filter, Offset, Measurement, Strain, Weighting are not supported	See manual
Configuration	Supported	APIs for storage devices are not supported

Dio	Supported	Not supported
Events	Supported Pulse not supported	Supported Pulse not supported
Measurement	Supported DataFormat: EUReal32, RawInt32 FIFOMode: Stop only	Supported DataFormat: EUFixedPoint32, RawInt32 FIFOMode: Stop only
Sampling (Measurement and Channel interfaces)	Supported Multipass, Oversample not supported Prescaler: must be 1	DownsamplingFactor, FilterType, Get/SetFilterCoefficients, Multipass, Oversample not supported
Platform	Supported	Supported
ReferenceOscillator	Supported PXIClk10 not supported	Supported OutputEnabled not supported
SelfTest	Supported	Not supported
Start	Supported	Supported
Storage Devices	Supported	Not supported
StreamingData	Supported	Supported
Sync	Supported	Supported
Temperature	Supported	Supported
Time	Supported	Supported
Trigger	Supported MaxQueueSize, QueueEnabled not supported	Supported MaxQueueSize, QueueEnabled not supported

TABLE 4-1: SUPPORTED FUNCTIONS IN COMMON DIGITIZER API

DRIVER STRUCTURE

MEASUREMENT

This section provides information related to configuring the basic measurement setup and control. The basic measurement configuration and control can be done through the driver's Measurement interface. The Measurement interface configures parameters that are global to entire system, rather than individual channels, or instrument modules when more than one module is included in the driver.

The parameters the user can set using the Measurement interface are:

- Sampling parameters, including ADC sampling rate, digital decimation filters, span, and data record size
- Number of data acquisition records at each trigger event
- FIFO mode of operation
- Data format

The Measurement interface can be used to query the current measurement state information:

- Measurement state machine state
- Total number of records available in FIFO

Methods to control measurement, such as:

- Initiating measurement
- Aborting measurement
- Retrieving acquired data

CHANNELS AND CHANNEL GROUPS

This section provides information related to using channels and channel groups. For more detailed information, see the online help file provided with the Digitizer driver.

The Channels interface contains both channel objects and channel group objects in the same array. A channel object represents an individual analog input channel. A channel group object represents one or more analog input channels as a group. When a driver is initialized or reset, the repeated capability contains the analog channels, one channel group representing all of the analog channels, and one or more channel groups representing the analog channels from each digitizer model in the driver session. For example, when there are two EX1401 instruments and one EMX-4350 in a single driver session, the *Channels* interface contains an array totaling 39 channel objects. Those channels are 32 individual EX1401 analog input channels (16 from each EX1401), four EMX-4350 individual analog input channels, one channel group object that represents all 36 analog input channels, one channel group for all 32 EX1401 inputs, and one channel group for all four EMX-4350 inputs. These channel groups are named “All”, “EX1401”, and “EMX-4350”.

The channel array is created in ascending slot order for modular instruments (such as the EMX family). The first element in the array is the first analog input of the digitizer card that is installed at the lowest slot in a chassis. When more than one instrument is included in the total system, the channel order is determined by the resource string used in the driver’s *Initialize* call.

The individual channel objects are used to configure or query individual input channel properties.

The channel group objects can be used to configure multiple channels to the same value. In general, the user can configure multiple channels faster using a channel group than setting channels individually. Querying the current setting through channel groups works only when all channels are set to the same value.

The channel name is defined as <slot no>!CH<channel no>. For example, 2!CH2 indicates the 2nd channel of a card installed at slot2 of a chassis. The predefined channel group names are “ALL” or an instrument model number such as “EX1401”. Optionally, the user can create new custom channel groups using *AddChannelGroup* method. When more than one instrument are in the session, the channel name of the 2nd instrument adds 100 to the slot number, such as 102!CH2, and 200 for the 3rd instrument, 300 for the 4th, etc. The RX0124 and RX0224 instruments each consist of only one digitizer slot, slot 2, to maintain compatibility with EMX products. The EX1401 instrument consists of a single digitizer slot called inst0.

The *NumChannels* property gives the total number of individual input channels, while the Count property is the total number of channel or channel group objects in the array.

START, ARM, TRIGGER, AND ALARM

The EX1401 implements a sophisticated Arm/Trigger model as show in Figure 4-1. This trigger model conforms to industry stand trigger models defined in the IVI Digitizer specification and IVI LXI Sync specification, with some additional features.

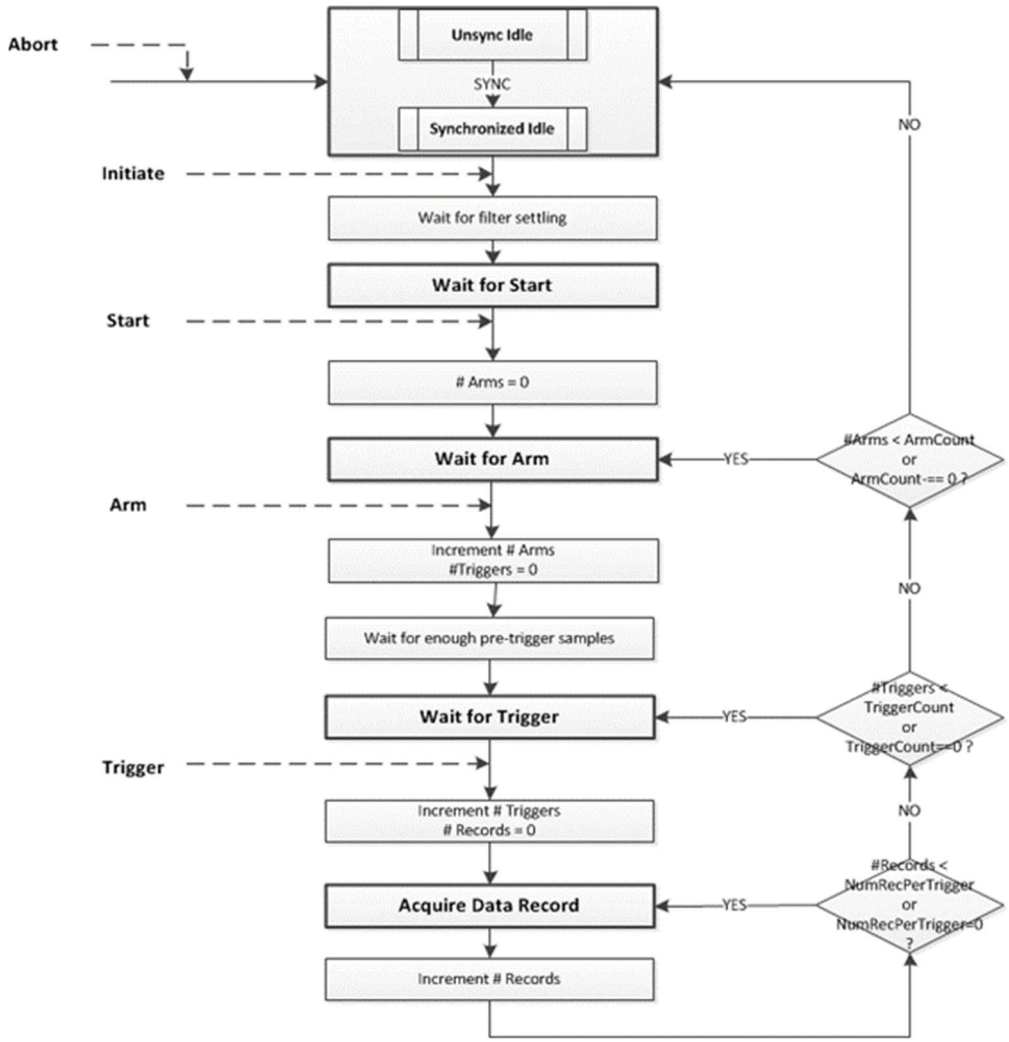


FIGURE 4-1 TRIGGER MODEL

Sync

Sync is an event that synchronizes the entire system. The *Sync* interface is used to configure the synchronization between cards. All cards are simultaneously started by the SYNC signal and then they synchronize the state machine transition with each other through a coordination signal. The *Line* and *CoordinationLine* properties define which PXI trigger lines and/or Alarms to use to send these signals.

Start

Once the measurement is initiated by the Initiate command, the instrument completes all preparation and becomes ready to start taking data immediately. Then the state machine moves to the *Wait for Start* state. The *Start* interface provides methods and properties to advance to the next state. The amount of time it takes to reach to *Wait for Start* after measurement *Initiate* command varies depending on the measurement configuration. For example, it takes longer when the measurement sample rate (or measurement span) is low because the filter settling time is longer. The *Start* interface is useful when the user wants to have the instrument complete all the preparation and hold in that state, so that it can start taking data immediately without any delay.

Arm

The instruments must be armed before triggering data acquisition. The *Arm* interface is used to configure this arming condition. The *Sources* property in the *Arm* interface defines the arming event sources. The default arming source is *Immediate*, which means automatic arming. The *SourceOperator* property allows the user to define an arming condition by logically combining multiple arming sources. The *Delay* property defines amount of time the instrument waits before moving out from *Wait for Arm* state after the defined arming conditions are met. The *ArmCount* property defines how many times the measurement repeats arming and triggering before it completes. The default is once. Setting *ArmCount* to 0 forces the measurement to repeat arm and trigger indefinitely until it is aborted by *Abort* command.

Trigger

Data acquisition begins when a triggering condition is met. The triggering condition is configured using the *Trigger* interface. Similar to Arm interface, the *Sources* property in the *Trigger* interface define the triggering event sources. Trigger sources can be logically combined using *SourceOperator* in the *Trigger* interface. The *Delay* property defines the amount of time between the trigger event and the beginning of the data acquisition. The *Delay* value can be negative indicating pre-trigger data acquisition. In this case, the acquired data block starts earlier than the trigger event. This is achieved by buffering the data in the instrument's FIFO prior to the trigger event. For more information, see the Data Acquisition section.

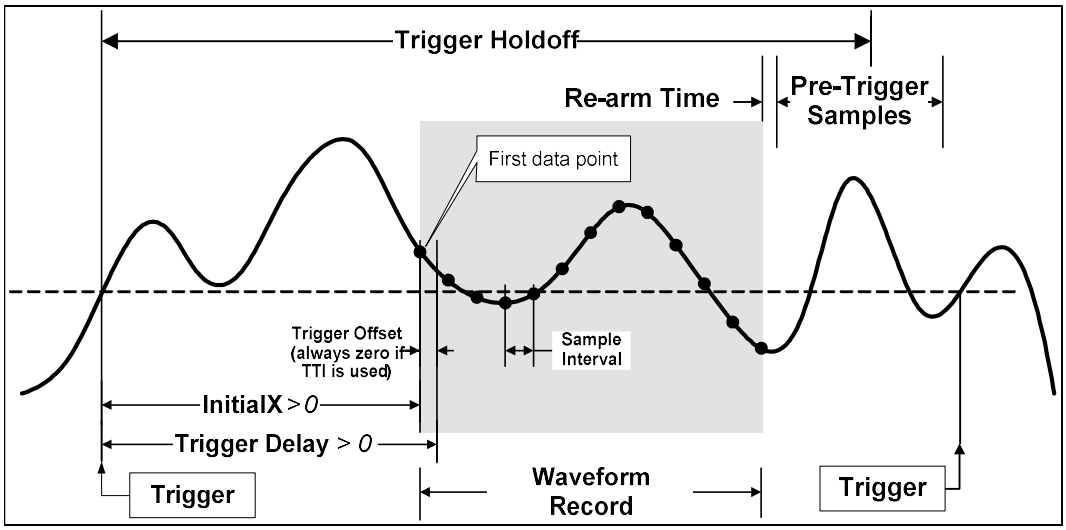


FIGURE 4-2: POSITIVE TRIGGER DELAY

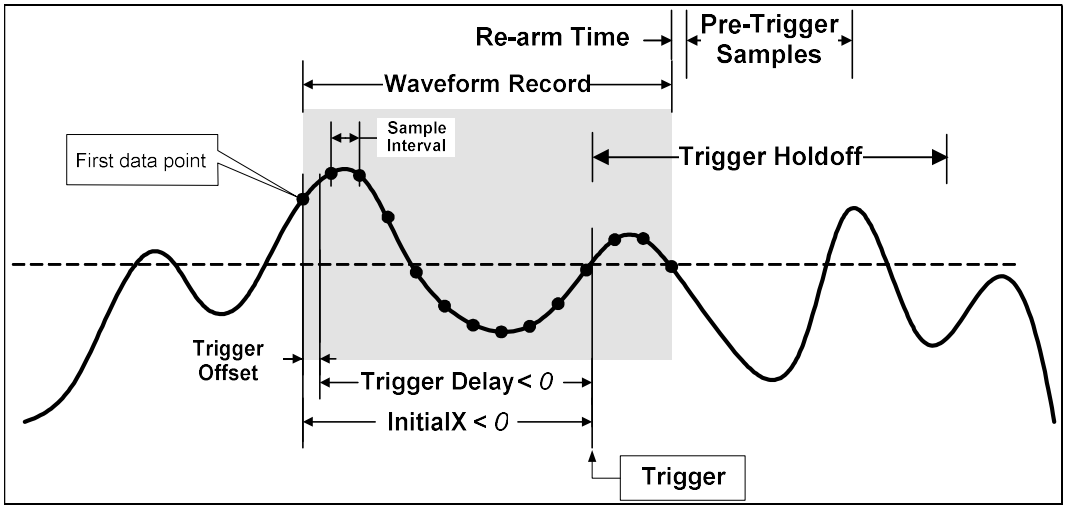


FIGURE 4-3: NEGATIVE TRIGGER DELAY

The *TriggerCount* property defines how many times the trigger events are accepted and data blocks are acquired. After "*TriggerCount*" triggers are processed, the measurement waits for the next arming condition or finishes. The *HoldOff* time specifies the minimum amount of time the measurement has to wait before it can be triggered again once a trigger is detected. Any trigger events that occurred during the *HoldOff* time are ignored. When the specified *Holdoff* time is shorter than one data record period, the two successive data records may be overlapped.

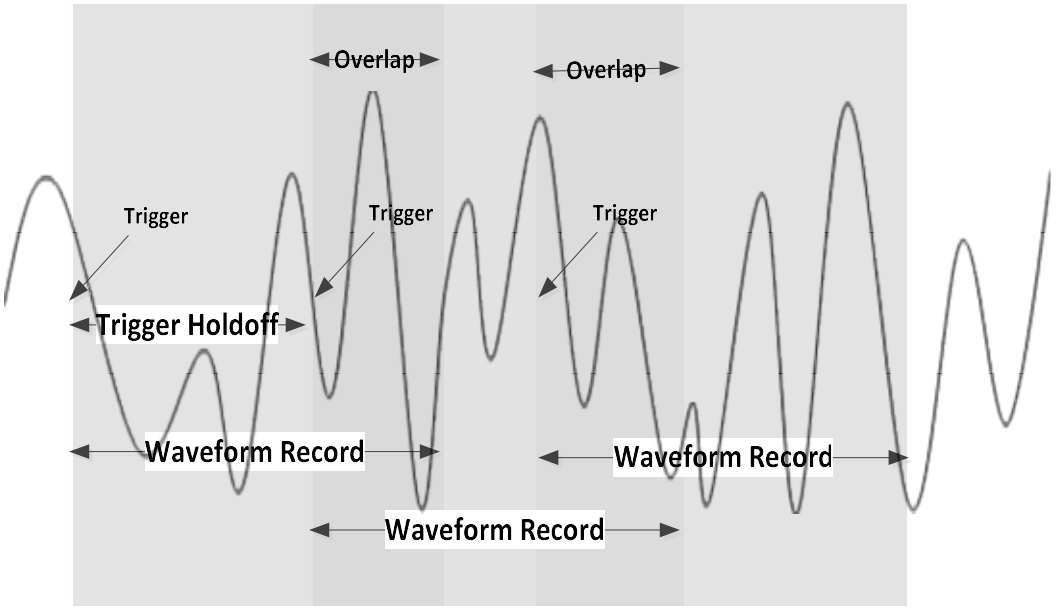


FIGURE 4-4: OVERLAPPED DATA ACQUISITION

Trigger HoldOff

The ability to configure the TRIG event source to be an external event such as a Digital I/O channel level or a Trigger Bus channel edge is a powerful test feature, allowing measurements to be precisely correlated with external events. External events, however, could nominally be generated at a rate far faster than the EX1401 can completely and correctly execute the DEVICE layer. To prevent the instrument from being overdriven, the trigger model contains an internal holdoff timer. Once the trigger event has been satisfied, this timer disables the recognition of all trigger events for a time

period of 1 sample period. Trigger events that occur during this period are ignored, not buffered. This is similar in concept to the fact that, for example, additional ARM events are ignored if the trigger model is not specifically waiting for an ARM event. Due to this action, triggering the EX1401 with a burst of external pulses that exceeds the configured sample rate will result in not only fewer readings than trigger events, but also a reading rate that is potentially far less than the maximum rate.

Consider an example in which the trigger model is set to the following configuration:

Start Source	Immediate
Arm Source	Immediate
Arm Count	1
Arm Delay	0
Trig Source	DIO Channel 0 Positive Edge
Trig Count	100
Trig Delay	0
SampleRate	1000

Once initialized, the EX1401 is driven by a burst of 100 positive edge transitions at a rate of 1.5 kHz. At 1.5 kHz, the time between trigger events is 667 µs. Since this time is less than 1 ms, every other trigger event will be ignored. Consequently, this burst will generate 50 readings at a rate of 750 Hz. Note that the actual reading output rate is far less than the 1 kSa/s maximum rate. To achieve the maximum output rate, the TRIG event source should be set to Immediate.

Start, Trigger and Arm events

There are three events that control the progress through the trigger model: The Start, Arm, and Trigger events. Each of these events can be programmed independently to be activated from any of the External Trigger, Digital I/O port, LAN events, Channel Analog Levels, and LXI alarms. In addition, each event can be programmed to be Immediate, creating a permanent satisfaction of the event monitor. Each event monitor can also be bypassed on command with the issuance of a Software Start, Software Arm, or Software Trigger, as appropriate. The full list of sources includes:

- Digital Sources:
  - Immediate
  - Software
  - ALARM0-1
  - EXT
  - DIO0-7
  - LAN0-7
- Analog Sources:
  - CH1 to CH16

The Start event source can be any one of the Digital sources, and is always a Falling Edge event.

The Arm event source can be any combination of the Digital sources, via either a Boolean AND or a Boolean OR of all enabled sources. Each enabled source can be a High Level, Low Level, Rising Edge, or Falling Edge event.

The Trigger event source can be a combination of either any of the Digital or any of the Analog sources, via either a Boolean AND or a Boolean OR of all enabled sources. Each enabled source can be a High Level, Low Level, Rising Edge, or Falling Edge event. Analog and Digital trigger sources cannot be enabled at the same time.

The Digital I/O port and the External Trigger monitor the digital hardware ports on the rear panel of the instrument. An Arm or Trigger event can be controlled by any combination of the eight channels of each port.

LAN Events are triggered through the eight LAN Event channels via Ethernet packets (UPD/multicast or TCP messages). They are configured in a manner similar to the Digital I/O port. These events can occur in "past time", "now", or "future time". "Past time" events have an IEEE 1588 time that occurred in the past. These will cause data starting from the time indicated in the packet to be marked for retrieval. But, if the instrument was not in the *WaitingForTrigger* state at the specified time, the packet will be ignored. "Now" events have a IEEE 1588 time of "0", indicating that the event will occur immediately after it is received. Because they have a time of "0", the event log will only identify when this event was received. "Future time" events have an IEEE 1588 time that has not yet occurred. Because these events occur in the future, they can be prepared for and provide a better response time than either "past" or "now" events. For more information on LAN Events, please see the LAN Events Menu in Section 4.

LXI alarms are specified by IVI 3.15, IVILxiSync specification. The LXI alarm will cause an event based on IEEE 1588 time and always occur at the pre-programmed time. The alarm period can be set for this event as well, allowing the LXI alarm to fire repeatedly at a defined interval.

NOTE:	The extensive flexibility of the trigger model system permits the creation of very specialized trigger conditions, which is a powerful application tool. However, it also permits the creation of trigger conditions that would be very difficult to satisfy in practice. For example, if edge conditions are specified on multiple digital hardware channels, the edges must occur within 25 ns of each other to be recognized as having occurred simultaneously.

Alarms

LXI alarms are a mechanism that generates events at a fixed time interval as specified by IVI 3.15, IVILxiSync specification. When the *Enabled* property is true, the alarm starts at the time specified by *TimeSeconds* and *TimeFraction* and repeats for *RepeatCount* times. The *Period* property defines the interval between the two successive alarm events. Setting the *RepeatCount* property to 0 causes the alarm to continue firing at the specified *Period* until the *Enabled* property is set to false. Setting the *Period* to 0 causes the alarm to fire only once. The alarm properties can only be modified when the alarm is disabled.

As an extension to the LXI alarm capabilities, the EX1401 also supports "now" alarms (similar to "now" LAN events). Setting the *TimeSeconds* and *TimeFraction* properties to 0 causes the alarm to fire as soon as it is enabled.

Alarms can be used as an arm or a trigger event source.

RETRIEVING DATA

The Digitizer driver provides two ways to retrieve data from EX1401. By default, the acquired data is stored in the instrument's FIFO buffer. The data in the FIFO can then be read using the standard *Read* method. An alternative option is to use data streaming. The streaming mechanism makes it possible to transfer data faster than the standard FIFO *Read* method.

FIFO Read

Once the measurement is triggered and data becomes available in the instrument's FIFO buffer, data can be retrieved using the *Read* method in the *Measurement* interface. The *Read* method returns the specified number of data records from all enabled input channels in a channel order in the *Channels* array. The *NumFIFORecords* property in *Measurement* interface returns the number of data records currently available in the instrument's FIFO buffer. This value decreases when the data is retrieved by the host, and increases when new trigger events are processed. FIFO buffer overflow may happen when the trigger events arrive faster than the host can retrieve data. See the *FIFO* description in the Data Acquisition section for more information.

Streaming

Streaming data is an alternative method for retrieving data from the EX1401. Unlike the FIFO read function, instruments send new data records to the host PC as soon as it becomes available when streaming data. The data is kept in the host memory buffer managed by Digitizer driver. The data in this memory buffer is then retrieved to the user's application through the *MemoryRead* method. The streamed data can be directly written into disk files or passed to a user's callback method. In order to use this streaming mechanism, it must be enabled by calling the *EnableStreaming* method in the *StreamingData* interface.

The key advantage of the streaming method over the FIFO Read method is data transfer speed.

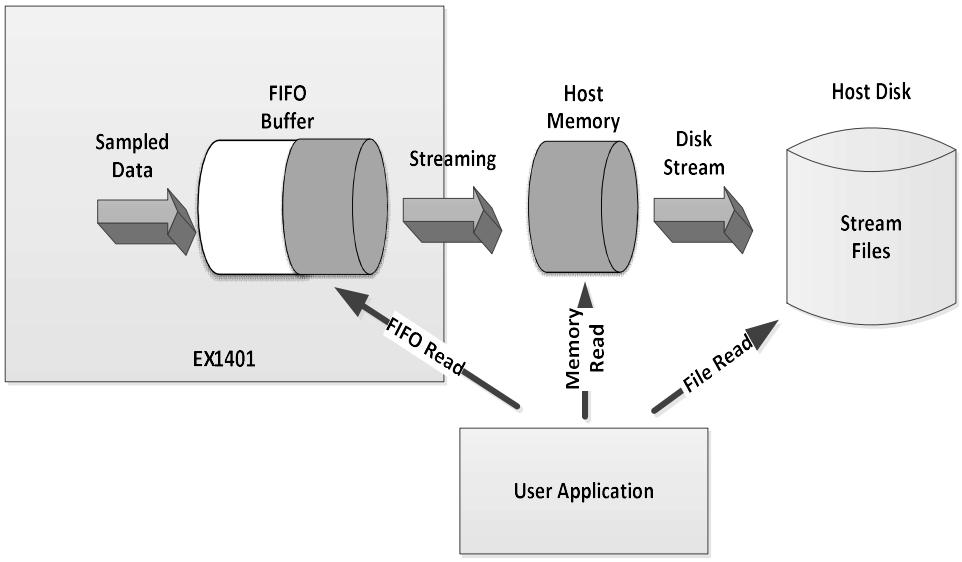


FIGURE 4-5: FIFO READ AND STREAMING

REFERENCE CLOCK AND TIME STAMPS

The *Source* property and *TimestampSource* property in the *ReferenceOscillator* interface configure the reference oscillator to generate an ADC sampling clock and data time stamp clock. The PXIe_CLK100 (100 MHz) reference signal is used by default. When the system is synchronized to the IEEE 1588 PTP grand master via Ethernet, the IEEE 1588 clock can be used as a reference oscillator be selecting "System".

LXI and LAN Events

The EX1401 can act as an LXI device. These instruments can be synchronized to an IEEE 1588 PTP grand master clock. They can be armed or triggered by LAN events or they can generate LXI LAN events to synchronize with other LXI devices through the IVI-LXISync interface defined in the IVI driver specifications.

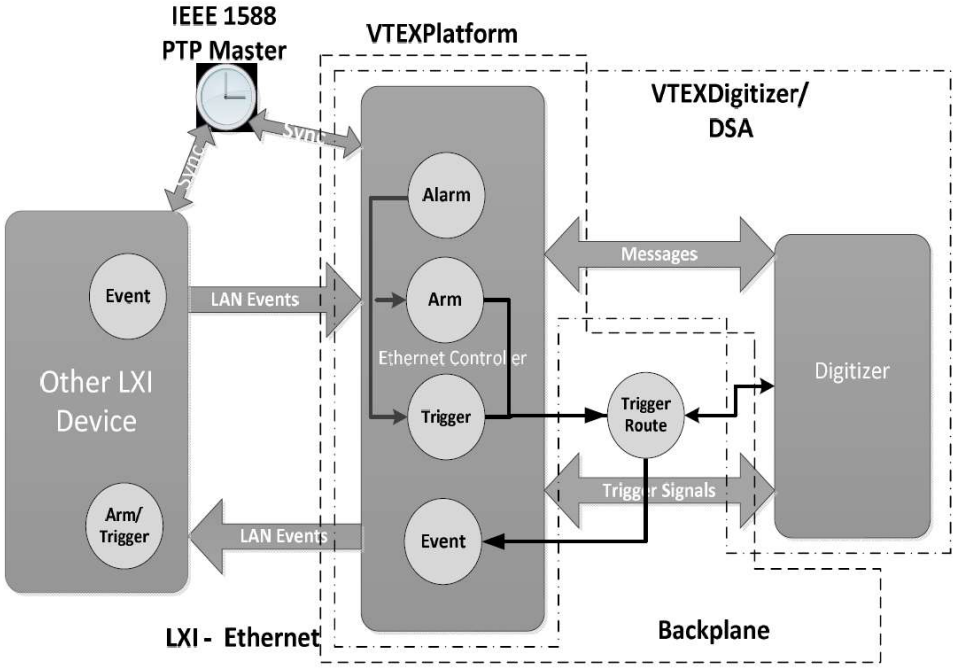


Figure 4-6: LXI and LAN Events

IVI Class Compliant Interfaces

In addition to the IVI-LXISync interface, the VTEXDigitizer/VTEXDsa drivers expose the IVI-Digitizer and IVI-Scope class compliant interfaces. These interfaces are exposed for the instruments interchangeability, but their use is not recommended. These IVI interfaces do not support the full capabilities of the EX1401's sophisticated trigger model and many other features.

Multiple Instruments

Initializing with Multiple Instruments

Unlike many typical instrument drivers, the Digitizer drivers allow multiple EX1401 devices and other EMX devices to be controlled as if they were a single, collective instrument. The user can initialize a single driver for two EX1401 devices and treat them as a single, 32-channel instrument instead of creating two driver sessions with 16 input channels each. Multiple types of device can also be included in the driver session.

When initializing the driver session, the resource name is passed as an argument to the *Initialize* method that specifies which instruments will communicate. The resource name has the following syntax:

```
<address 1>[ ::<slot 1>,<slot 2>,..,slot N> ] | <address 2> [
::<slot 1>,<slot 2>,…,<slot M> ] | …
```

Where:

<address x> is the IP address or host name of the EX1401 or EMX-2500 controller (of the PXIe chassis, where EMX series cards are installed)

<slot x> is the slot number identifier of the instrument in a chassis. The slot number identifier is a string such as "slot0_5" which indicates the 5th slot of the first chassis controlled by an EMX-2500. An identifier such as "slot1_6" indicates the 6th slot of the 2nd chassis extended by a bus extender. (Bus extenders are not supported by all devices.)

The slot numbers are optional. When no slot numbers are specified, all supported instruments within the chassis will be used. The slot number for all EX1401 instruments is "inst0", but this can always be safely omitted.

When connecting to more than one EX1401 or EMX-2500 controller, the addresses must be concatenated with the "|" (pipe) character.

The resource string to connect to a particular device can be found on the Index**Error! Reference source not found.** web page.

MULTIPLE INSTRUMENT COORDINATION

When the driver session contains multiple EX1401 and EMX devices, the *Sync* and *ReferenceOscillator* interfaces must be used to synchronize the sampling clocks and trigger models on each device to have the best sample-to-sample alignment during measurements.

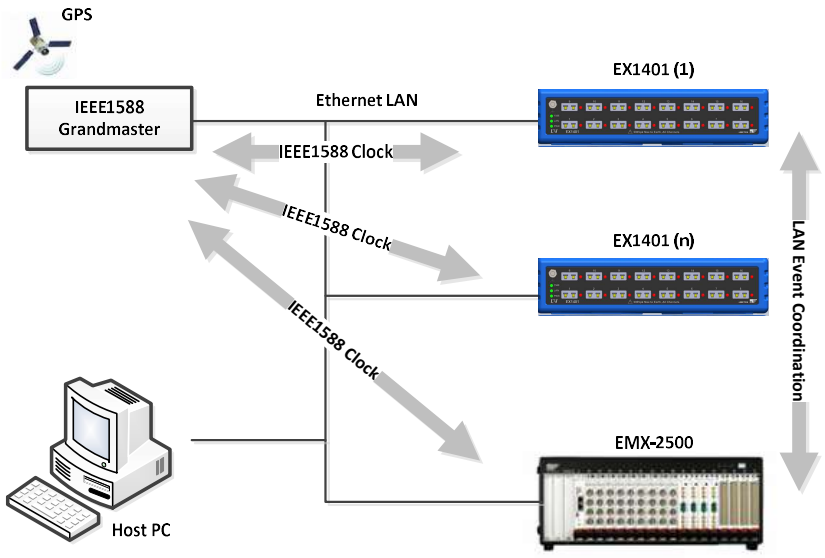


FIGURE 4-7: LAN COORDINATION

Before enabling LAN coordination, each EX1401 and EMX-2500 controller must be configured to use PTP2 as the time source (see Time Configuration in Section 4). All devices must use the same value for the PTP Domain. They must also be configured to use the same value for LXI Domain via the web page or using the Platform driver.

After opening the Digitizer/DSA driver session, the *ReferenceOscillator.Source* and *ReferenceOscillator.TimestampSource* properties must be set to "System" (IEEE 1588). The

Sync.Line property must be set to a comma-separated list of sources for the sync signal, such as "ALARM0" or "ALARM0,PXI0". The *Sync.CoordinationLine* property must be set to a comma-separated list of signals (beginning with "LAN") to use for the coordination subsystem, e.g., "LAN" or "LAN,PXI0". Note that EMX devices require specifying a hardware line in addition to LAN when setting the *Sync.CoordinationLine* property. See the Digitizer/DSA driver documentation for more information.

The most convenient way to ensure the correct settings for synchronization/coordination is to configure the desired arm sources, events, and trigger sources, then call the *Sync.AutoConfigure* method. This selects the best values for the *Sync.Line* and *Sync.CoordinationLine* properties based on the devices in the driver session. See the Digitizer/DSA driver documentation for more information.

LAN coordination may cause unexpected confusion in rare circumstances if the devices are separated by a long distance or network communication is slow. For example, when an analog channel detects a trigger, it sends a LAN message to all devices so that they trigger at the same time. If another channel from a different device also detects a trigger condition before it receives the LAN event from the device that detected the previous trigger condition, the multiple triggers cannot be processed correctly. In order to avoid this scenario, the user may need to set restrictions so that only certain channels can detect trigger events.

DATA ACQUISITION

DATA FLOW

The EX1401 instruments have a dedicated A/D converter at each analog input channel. The A/D converter samples analog data at fixed frequency specified by a multiple of the *ClockFrequency* (F_C). The output data rate of the ADC is F_C. The digitized data by the A/D converter can then be decimated and filtered by any one of three selectable types of digital filters until the signal is band limited to the desired frequency span and the sample rate (F_S). These band-limited samples are constantly sent to the FIFO memory buffer located in DRAM.

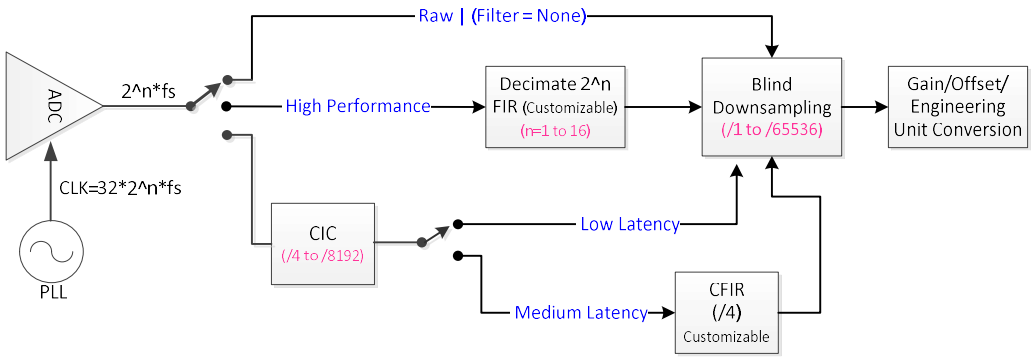


FIGURE 4-8: DECIMATION FILTER AND MEASUREMENT SPAN

FIFO

The decimated and band-limited samples by decimation filters are temporarily stored in a circular buffer (or FIFO) until the data is read out and transferred to the host.

Figure 4-9 illustrates the circular data buffer (FIFO). The figure shows three unread data records in the data buffer. The white *unused space* and *over-writable space* are the areas where new data can be written until this data buffer becomes full.

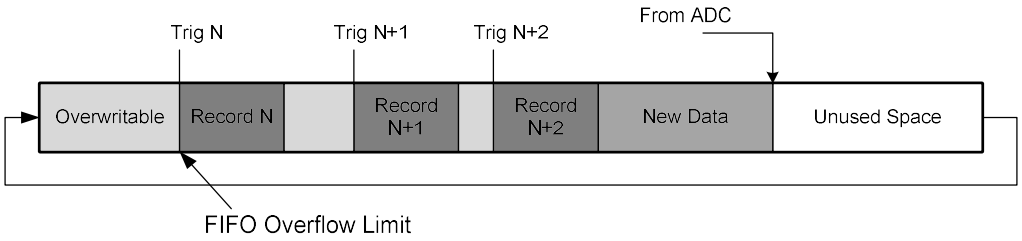


FIGURE 4-9: CIRCULAR FIFO

When the FIFO buffer is full and there is no more space to write new data to the FIFO, the measurement is aborted. After the last data record in the FIFO is read, a FIFO overflow error will be issued to indicate why the acquisition was stopped.

DATA STREAMING

The Digitizer driver comes with an optimized data-reading interface for high speed and/or low-latency acquisitions. This interface relies on a separate thread which receives data asynchronously from the instrument as soon as it is available and acts on it immediately based on user-set preferences. There are three streaming modes, any of which can be enabled at the same time.

Memory Streaming

Memory streaming is the default mode for these instruments. When the user enables Streaming without any configuration, the data is streamed into a dynamically allocated buffer on the host PC and then retrieved via a Read-like interface. This is the fastest streaming interface, since memory is the fastest storage device on the PC. However, this mode is unsuited for long acquisitions because it can grow beyond the memory limits of the device and start paging to disk. The internal buffer grows as needed but does not shrink until streaming is disabled.

Additionally, this mode can be set to watch only select channels of interest. If the *MemoryChannelsList* property is set, the data for only the selected channels will be streamed to memory.

If another type of streaming is enabled while memory streaming is enabled, memory streaming is disabled unless the *MemoryChannelList* property is set.

Disk Streaming

Disk streaming is intended for high performance applications and/or long acquisitions. When enabled by setting a filename, the driver optimizes the data path by not converting the data from the native VRT data format. The data is written to disk in the HDF5 data format. For more information on HDF5 file formats and tools, visit the HDF Group's website: https://www.hdfgroup.org.

The Digitizer driver uses an HDF5 file hierarchy that is very similar to the layout used for the Data Logger feature. See HDF5 File Hierarchy in Section 6 for more details.

The disk streaming file includes several HDF attributes that describe the instrument configuration at the time that an acquisition was initiated. Additional user-defined attributes can be set by using the *SetCustomAttributes* method. The *GetCustomAttributes* method allows the user to inspect the attributes that are currently set. *RemoveCustomAttribute* and *RemoveAllCustomAttributes* can be used to remove attributes that are no longer needed.

If *Measurement.Initiate* is called multiple times without changing the *Filename* property, the existing file will be overwritten with the new acquisition data.

Disk streaming has the same limitations as the underlying filesystem. For example, a FAT32 filesystem cannot support files larger than 4GB. If disk streaming is used on a FAT32 filesystem

and the file grows too large, errors and data loss may occur. In addition, disk streaming throughput may suffer when the underlying filesystem is very slow, such as a USB 2.0 external drive.

Callback Streaming

Callback streaming is most useful in low-latency situations. In this mode, the user registers one or more callback functions, which are called with available data when it is ready. The user's code may then act on the data. To register a callback, the user will have to override the COM abstract interface (when using the IVI driver) or C++ pure-virtual callback class (when using the Linux driver), and then pass this class to the *RegisterStreamingCallback* method. The data is returned in the same format as the *MemoryRead* method, as can be determined from examining these classes.

Support for registering a callback to receive data only from certain channels, similar to using the *MemoryChannelList*, is scheduled for a future driver release.

SAMPLING RATES

The properties in the *Sampling* interface configure the A/D converter and decimation filters to specify the sampling rate and frequency span of the data to be acquired. Some properties in this interface are interrelated. Changing one property value can affect the other.

There is a *Sampling* interface in the *Measurement* interface as well as the individual *Channel* interface. The properties in the global *Sampling* interface that apply to all channels as well as DIO can be configured from the *Measurement* interface, while the *Channel* interface allows the user to configure each channel independently.

ClockFrequency

The *ClockFrequency* specifies the A/D conversion rate. This property determines the highest *SampleRate* of the data acquisition session. The highest rate can be achieved by bypassing all decimation filters. The EX1401 supports all integers from 10000 to 20000 as valid values of *ClockFrequency*. *ClockFrequency* can also be set to -1 to allow the firmware to choose the value automatically based on the requested *SampleRate*. *ClockFrequency* is a global parameter. It cannot have different values for each channel.

Prescaler

This is the sampling rate divider before the ADC data is decimated by the ½ decimation filter stages. The EX1401 only supports a value of 1 for *Prescaler*, which has no effect on measurement data.

DownsamplingFactor

This is the amount of unfiltered downsampling that will be performed after the decimation filtering by the selected *FilterType*. The EX1401 supports all integers from 1 to 65536.

FilterType

This specifies the type of digital filter that will be used to decimate and filter the data. Four options are available; *High Performance*, *Medium Latency*, *Low Latency*, and *None*. *None* disables all digital filtering, such that effective *SampleRate* is equal to *ClockFrequency* divided by *DownsamplingFactor*. *HighPerformance* is an FIR filter with 0-16 divide by 2 stages. This provides optimal performance but has high group delay. The decimation ratio can only be powers of two up to 2^{16}. This filter's response can be customized by providing normalized filter coefficients. *LowLatency* is a CIC filter capable of any integer decimation ratio from 4 to 8192. This provides the lowest group delay, but is only suitable for use with DC inputs. *MedLatency* pairs the CIC filter with a Compensating FIR (with decimation ratio of 4) at its output. This increases the group delay, slightly, while providing a better response across a variety of input frequencies. Valid decimation ratios are all multiples of 4 from 16 to 65536. The *MedLatency* filter's CFIR can also be customized by supplying normalized filter coefficients.

SampleRate

This is the effective data rate. The inverse of *SampleRate* specifies the interval between data samples that the user can obtain. The *ClockFrequency*, *DownsamplingFactor*, and *SampleRate* determines the amount of decimation and filtering performed by the filter indicated by *FilterType*. Some instruments support setting different *SampleRate* values on channels in a single instrument. For EX1401, the *SampleRate* is a global property and will always be the same for all channels in the same instrument. The decimation ratio of the selected filter will be set to *ClockFrequency* / *DownsamplingFactor* / *SampleRate*, rounded down to the next valid value for the chosen *FilterType*.

Span

The *Span* is the nominal frequency range of the acquired signal. The value of *Span* is determined by the decimation filter's cutoff frequency. The ratio between *Span* and *SampleRate* varies based on the selected *FilterType*. See the instrument specifications table for the precise value for each filter.

FilterCoefficients

The normalized filter coefficients of the *HighPerformance* and *MedLatency* filters can be programmed by the user to achieve optimal results for their particular application. These are each 32-tap FIR filters with 64 coefficients.

GroupDelay

The *GroupDelay* parameter specifies the delay of each stage of the FIR and CFIR filters used by the *HighPerformance* and *MedLatency* filters, respectively, in units of undecimated samples. By default, this value will be correct for the preprogrammed value of *FilterCoefficients*. If, however, a custom set of coefficients is supplied, this property should be set with the correct group delay for those coefficients. This allows the firmware to perform group delay compensation on measured data correctly with the customized filter response.

RecordSize

The *RecordSize* specifies the number of data samples read back from the instrument at a time. The total number of data samples captured for each trigger is equal to the product of *RecordSize* and the *Measurement.NumRecordsPerTrigger* property – that is, *NumRecordsPerTrigger* records are captured, and each is of size *RecordSize*. Figure 4-9 shows the case where *NumRecordsPerTrigger* = 4. As a special case, when *NumRecordsPerTrigger* is set to 0, an infinite number of data records are returned in *RecordSize* sample chunks after a trigger event until the measurement is aborted.

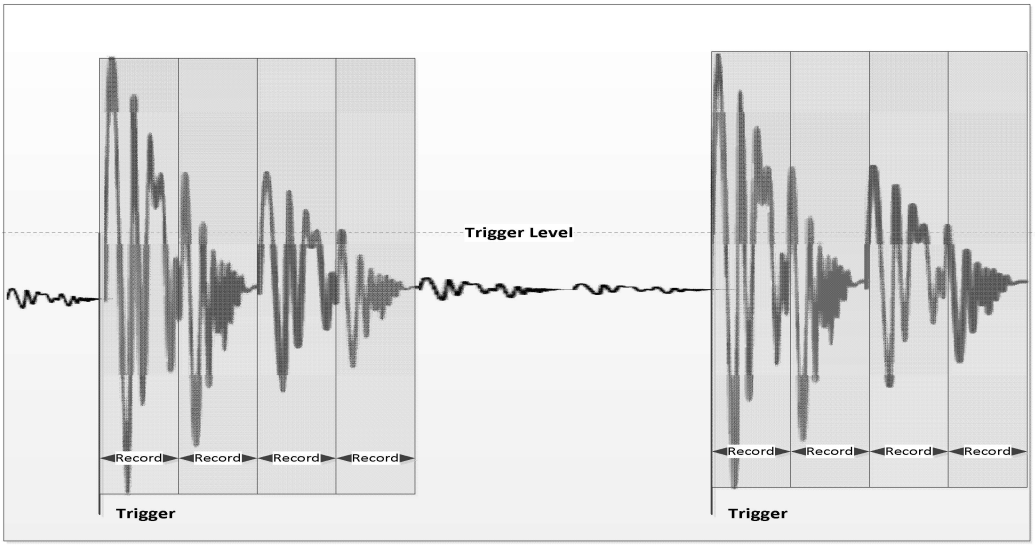


FIGURE 4-10: RECORD SIZE AND *NUMRECORDSPERTRIGGER*

With EX1401, the minimum *RecordSize* is 1 and the maximum power of 2 *RecordSize* is 32768. Since each data packet transferred from the instrument to the host contains one data record from each ADC channel, in general, the user can achieve higher data transfer using a larger *RecordSize* value due to reduced overhead, but this affects the data update interval, as the amount of time to acquire one data record is: T = *RecordSize*/*SampleRate*.

Setting The Sample Rate

There are four key properties to configure when setting the EX1401's sample rate. These are *ClockFrequency*, *FilterType*, *DownsamplingFactor*, and *SampleRate*. *ClockFrequency* defines the rate at which the instruments ADCs produce data. The other properties all define how that data is digitally decimated and filtered. When possible, choosing higher *ClockFrequency* and higher amount of decimation for the same final sample rate is generally better, providing better signal characteristics. If the *ClockFrequency* is set to -1, the firmware will automatically select the largest possible value that best achieves the user-specified *SampleRate*. *FilterType* selects which type of digital decimation filter will be used, and will affect both the granularity of available sample rates and the spectral performance of the decimated output. *DownsamplingFactor* is applied after all digital filtering to reduce sample rate with no group delay by simply throwing away N-1 in N samples. Finally, setting *SampleRate* will specify the decimation ratio of the chosen filter so that *SampleRate* = *ClockFrequency* / DecimationRatio / *DownsamplingFactor*. DecimationRatio will be rounded down to the next valid value (and thus *SampleRate* rounded up) if the supplied value is not exactly possible.

DIO Sample Rate

The EX1401's DIO port can record its input state at the same rate as the analog input channels. Because this data is purely digital and binary, it cannot be decimated. All DIO data is downsampled with no filtering such that the DIO sample rate is always equal to the analog channels' final sample rate. For that reason, only *ClockFrequency* and *SampleRate* are available in the *DIO.Sampling* interface – *FilterType* is not supported. Attempting to set either the channel or DIO sample rate will always cause the other to be set to the same value.

OVERLOADS AND OPEN TRANSDUCER DETECTION

When the analog signal amplitude exceeds the input range, the digitized samples are truncated resulting in a distorted waveform. To avoid this, users can increase the input range of the instrument, attenuate the signal level, or discard overloaded data from processing. Apart from over-range, there are other fault conditions that can invalidate measurement data, such as an open transducer. The EX1401 is capable of detecting some of these common fault conditions and reporting them, allowing the user to act.

The fault status can be queried from the Digitizer driver's API. The status can be indicated at the front panel LED, external trigger, and DIO outputs. The information is also associated to the acquired data record and returned in the *AdditionalData* string.

The Digitizer driver defines each fault status as an *Overload Status* bit field. The user can configure which fault conditions to reported, if an LED indicator is shown, or it can latch so that a momentarily fault won't be overlooked.

Bit Mask	Name	Description
0x00000002	Transducer Upper Limit	The signal is above the defined range of the transducer's EU conversion. This is either the limit of the NIST polynomials, for standard thermocouple types, or the user-supplied value of Channel.Tranducer.UpperLimit.
0x00000004	Transducer Lower Limit	The signal is below the defined range of the transducer's EU conversion. This is either the limit of the NIST polynomials, for standard thermocouple types, or the user-supplied value of Channel.Tranducer.LowerLimit.
0x00000008	User Upper Limit	The signal is above the user-defined value of Channel.Overload.UserUpperLimit, and Channel.Overload.UserLimitEnabled is True.
0x00000010	User Lower Limit	The signal is below the user-defined value of Channel.Overload.UserLowerLimit, and Channel.Overload.UserLimitEnabled is True.
0x00000020	Open Transducer	The OTD trickle current is enabled and has caused the input voltage to rise above the upper limit of the ADC's valid input range.
0x00010000	ADC Overload	The signal is outside of the ADC's valid input range, either too high or too low.
0x00100000	ADC Sync	The channel's ADC has become unsynchronized from the others in the instrument, likely due to electrostatic discharge. While this status bit remains set, the firmware is resynchronizing it.

TABLE 4-2: INSTRUMENT-SPECIFIC FAULT STATUS BIT SUPPORT

TIME STAMPS

During data acquisition, the EX1401 returns timestamps along with digitized analog data. The timestamps are created based on the *TimestampSource* clock specified in the *ReferenceOscillator* interface. When IEEE 1588 synchronized time stamps are desired, the *TimestampSource* property must be set to *ReferenceOscillatorTimestampSourceSystem*. Otherwise, the time returned will be the time elapsed since the SYNC signal was received.

When measurement data is retrieved, both a timestamp of the data record and a timestamp of trigger event are returned. The combination of *TimeSeconds* and *TimeFraction* parameters indicate the time of the first data sample in each retrieved data record. The time of trigger event is returned in the *AdditionalData* parameter.

Timestamp Source	Timestamp value	Resolution
System (IEEE 1588)	PTP or TAI (International Atomic Time)	40 ns
PXIe_CLK100	Elapsed time from last SYNC	40 ns

TABLE 4-3: TIMESTAMP SOURCE AND RESOLUTION

ADDITIONAL DATA

The additional information associated with the data records are returned as a JSON (Java Script Object Notation) array of name/value pairs:

```
[[JSON array for channel 1's first record], [JSON array for channel 2's first record], …]
```

The JSON object array for each channel is:

```
[{Object1}, {Object2}, …]
```

Each object is a list of name/value pairs:

```
{name1:value1, name2: value2, …}
```

JSON objects can be parsed using the following defined name strings.

Object	Name String	Value
Cold Junction Temperature Sensor Reading	Reference Junction	The temperature of the CJC sensor, in the same units as the channel data.
	timestamp_sec	The seconds portion of the timestamp of the first TC sample that this CJC measurement was used to compute.
	timestamp_frac	The fractional portion of the timestamp of the first TC sample that this CJC measurement was used to compute.
Over range	Over-Range	True when any overload status bit is set.
Trigger time	Trigger Timestamp Seconds	The trigger timestamp in seconds
	Trigger Timestamp Fraction	The fraction portion of the trigger timestamp.
Dropped trigger	timestamp_sec	The timestamp of when the trigger would have occurred.
	timestamp_frac	The fraction portion.
	Trigger Dropped	The channel name of the lost trigger.

TABLE 4-4: ADDITIONAL DATA JSON NAMES AND VALUES

MEASUREMENT PROCESS

MEASUREMENT SETUP

When the driver session is initialized by the *Initialize* method, the driver session is reset, or after the previous measurement is finished, the instrument is in the *Idle* state. While in the *Idle* state, the user prepares for the next data acquisition by configuring the setup parameters. For more information, please refer to IVILXISync standard API documentation

Start, Arm, and Trigger

Properties in the *Start*, *Arm*, and *Trigger* interfaces configure the data acquisition gating condition and timing. *Start* determines when the data acquisition starts and when the instrument is ready for the next acquisition. By the time of *Start*, all hardware configurations and filters settling need to be complete in order to ensure valid data is acquired.

Sampling Parameters

The sampling parameters are specified by properties in *Sampling* interface. *Sampling* in the *Measurement* interface configures parameters common to the entire system. Optionally, the user can configure the parameters of individual input channels using the *Channels* interface (with some restrictions).

Analog Front End

While some parameters can be changed during data acquisition, most configuration options should be performed prior to data acquisition to avoid data glitches. Most front end parameters can be configured independently for each input channel. The front end configuration includes input range, AC/DC coupling, IEPE current, voltage/temperature input function, and single-ended or differential input mode. Note that not all of these properties are supported by the EX1401.

MEASUREMENT INITIATION

After the user has completed configuring the instrument, the user can initiate the data acquisition process by calling the *Initiate* method in the *Measurement* interface. During measurement initiation, the instrument starts to prepare for the actual data acquisition. If the ADC has not been synchronized, the SYNC signal is sent and ADC then begins digitization. When the ADC's reference oscillator has been changed, the ADC sampling clock must be re-locked with the PLL. Filter settling also occurs at this time. Once the filters have settled and the instrument is ready to acquire valid data, the measurement moves to the *Wait for Start* state. The source of the *Start* event is *Immediate* by default. In this case, the measurement starts automatically. Otherwise, it must be started by an event specified by the *Source* property of the *Start* interface.

During this period, the digitized signal from the A/D converter is continuously filtered and discarded until the filters have settled. Once settled, the filtered data samples are stored in the internal data buffer.

MEASUREMENT LOOP

Once the measurement begins, the state machine cycles through arming and triggering for the number of times specified by *ArmCount* and *TriggerCount.* The measurement stops when the specified number of arm and trigger loops are completed, when it is aborted by an *Abort* command, or when the FIFO buffer becomes full and the FIFO mode is set to *Stop*.

ARMING

Arm is the gating condition to acquire data. In order to trigger data acquisition, the measurement must be armed first. There are several ways to arm a measurement. The default condition is to arm automatically (or *Immediate* arming).

Self-arming

When the *Immediate* arm source is enabled, the EX1401 arms by itself.

Arming by User's Command

The EX1401 arms by the *SendSoftwareArm* method when a *Software* arm source is enabled.

Arming at a Certain Time Interval

The EX1401 can be armed at a specific time interval using the ALARM0-1 arm sources. In addition to enabling the alarm as an arm source, it must be configured and enabled using the *Alarm* interface.

Arming by External Pulse

The EX1401 can receive an arm from the back panel trigger SMB connector by enabling the EXT arm source.

Arming from DIO Lines

The EX1401 can receive an arm event from the digital I/O port by enabling the DIO arm sources.

Arming from LAN Events by Other Instruments

The user, or another LXI device, can send LAN events to arm the EX1401 using the Digitizer driver. Alternatively, a LAN event can be sent to the EX1401 using the Platform driver.

TRIGGERING

When the measurement is armed and when there are enough digitized samples already collected in the FIFO for pre-trigger delay, the measurement becomes ready to receive a trigger event.

Self-triggering

When the *Immediate* trigger source is enabled, the EX1401 triggers automatically and acquires data records as soon as it is ready to receive a new trigger event.

Triggering by User's Command

The EX1401 triggers by the *SendSoftwareTrigger* method when a software trigger source is enabled.

Triggering at a Certain Time Interval

The EX1401 can be triggered at a specific time interval using the ALARM0-1 trigger sources. In addition to enabling the alarm as a trigger source, it must be configured and enabled using the *Alarm* interface.

Triggering by Analog Signal

The EX1401 is triggered when an analog signal at an input channel crosses the trigger threshold level. In order to trigger from the analog signal, the channel must be enabled as a trigger.

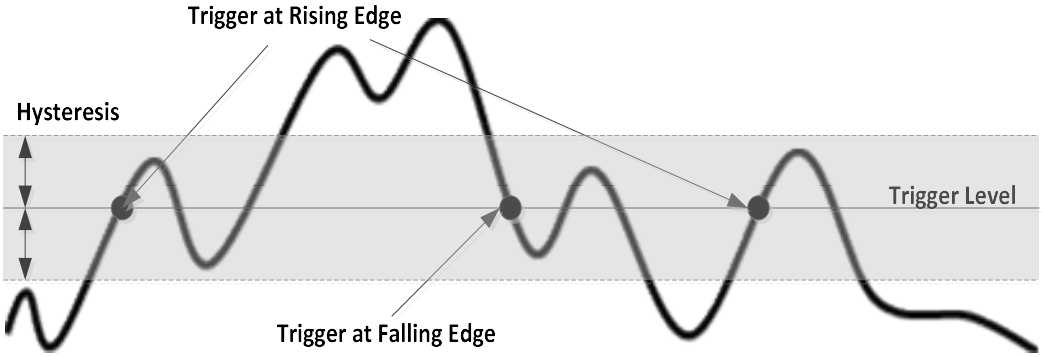


FIGURE 4-11: TRIGGERING BY ANALOG SIGNAL

Triggering by External Pulse

The EX1401 can receive a trigger from the back panel trigger SMB connector by enabling the EXT trigger source.

Triggering from DIO Lines

The EX1401 can receive a trigger event from the digital I/O port by enabling the DIO trigger sources.

Triggering from LAN Events by Other Instruments

The user, or other LXI device, can send a LAN event to trigger the EX1401 using the Digitizer driver. Alternatively, a LAN event can be sent to the EX1401 using the Platform driver.

DATA RETRIEVAL

After a measurement is triggered and at least one record of data (the number of samples specified by *RecordSize* property in *Sampling*) is available in FIFO buffer, it can be retrieved using the *Read* method in *Measurement* interface or via the *Streaming* method described in the Data Acquisition section in this manual. At each trigger event, the number of contiguous records specified by *NumRecordsPerTrigger* are acquired. Multiple records can be read separately or all in once if they are available in the instrument's FIFO buffer. The *Read* method in *Measurement* returns at least one record from all enabled channels.

When the user wishes to acquire continuous samples indefinitely after a single trigger event, set the *NumRecordsPerTrigger* property to 0 (infinite) and set FIFO mode to *Stop*. The data acquisition stops when the user aborted using the *Abort* method or when the FIFO buffer becomes full (FIFO overflow). In this setup, the user must retrieve data faster than the ADC data filling into FIFO in order to avoid FIFO buffer from overflowing.

Pipeline Delay and Latency

For high speed data recording, data transfer speed is key. For applications that require real-time data monitoring or processing, on the other hand, the data update rate becomes more important. A real-time closed loop control is an example. It is necessary to understand that there are delays at almost every stage of the data acquisition process. Some are within the instrument while others occur outside of the instrument, such as at the transducer or in the user's application.

The analog signal conditioning circuit introduces some delay before the signal reaches the A/D converter. Usually the delay in the analog section is small and negligible.

In the digital section, the digital filters in the A/D converter and decimation filters introduce a group delay. With the *HighPerformance* filter, it is about 192 ms at 156.25 Sa/s and increases at lower

frequency spans. The filtered data is transferred to the FIFO buffer at a specified interval (enough sample periods to cover at least 3.2 ms). Once a trigger is detected, the data in the FIFO can be read out to the user's application in blocks of *RecordSize* samples.

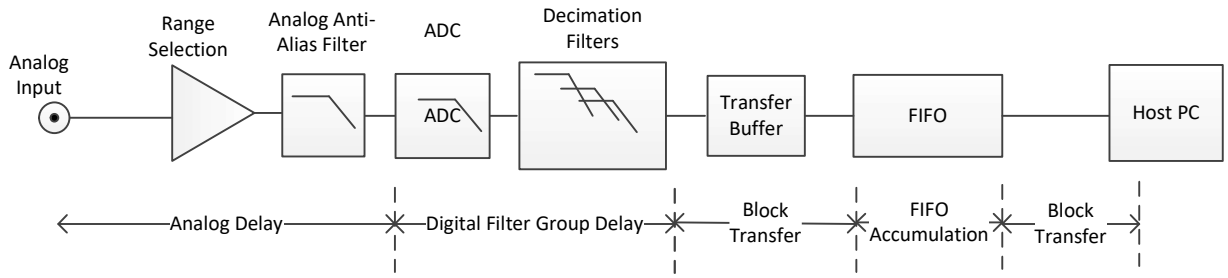


FIGURE 4-12: DELAYS IN DATA PATH

EVENTS

Events are an optional feature allowing the EX1401 to send notifications to the user, or other instruments, when a specified event occurs. The notification can be via LAN message, EXT trigger line, or DIO output. The user can specify an event when the measurement state is armed, triggered, finished, or when an overload condition is detected on one or more channels. See the Digitizer driver's online help for more information.

WHERE TO FIND MORE INFORMATION

DRIVER API REFERENCE

The complete driver's API reference is available as online help. Each driver comes with a .chm format help file in both Windows and Linux. Newer driver revisions also integrate the driver help content into the Microsoft Help Viewer, which is used by Visual Studio 2010 and later.

Each driver comes with several useful example programs in C++ and C#.

SPECIFICATION INFORMATION

The EX1401 conforms to many industry standards in both hardware and software architecture. Although products can be used without knowing these standards, some knowledge can be useful to take full advantage of VTI Instruments products.

- LXI specification is available from LXI consortium at www.lxistandard.org
- IVI driver specification is available from IVI Foundation at www.ivifoundation.org
- IEEE 1588 Precision Synchronization Protocol Standard at www.nist.gov/el/isd/ieee
- ANSI/VITA 49.0 (VRT) is specified as a part of VITA specification at www.vita.com

SECTION 6

OPERATION OF DATA LOGGER

INTRODUCTION

The EX1401 can be used as a data logger, in conjunction with an external USB disk. There are two major use cases to this feature. First, it can be used for standalone operation, where the instrument has no connectivity to host computer. Secondly, it can be used as non-volatile storage space, where the measured data will be stored during network / host computer fault.

USB DISK SELECTION AND PREPARATION

The standard USB host port available on EX1401 supports USB 1.1 and USB 2.0 standard disks, which are formatted with EXT2, EXT3, EXT4, VFAT/FAT32, and MSDOSFS file journaling formats.

NOTE	**Typical USB thumb/pen drives may be formatted using NTFS file system, which is widely supported on latest Windows OS. However, this file system is not yet supported by EX1401 instrument, and hence data transfer will not take place. Before using USB disk for critical applications, users are advised to test the configuration, using dummy test.**

The data will be stored in Hierarchical Data Format, HDF5 file format. HDF5 being an open standard data file format, a wide variety of tools are available to decompress, view and export the time stamped measurement data. For more information on HDF5 file formats and tools, visit the HDF Group's website: https://www.hdfgroup.org. The measurement data will be stored in single data file, and thus

The maximum current available on USB port is limited to 0.5A @ 5V. Hence, USB disks which requires more than 2.5W of power for their operation (such as USB Hard disk drives), should be externally powered.

USB DISK INSERTION AND SAFE REMOVAL

It is recommended to use an empty USB disk which is containing no other data files, other than device configuration file. Whenever a USB memory device that can support data logging is inserted into the USB port of EX1401 instrument, it will be detected by EX1401 instrument, which will add a menu page to the LCD menu containing "Data Logger: sda1", "Hold MENU to run" (assuming the device is mounted at sda1). Pressing and holding MENU button for 5 seconds on this page will then begin data logging. Pressing and holding MENU button again for 5 seconds, on this page, before completion, will abort data logging, and it is now safe to disconnect the USB disk. If USB disk is disconnected or instrument is powered off abruptly, while data storing operation is in progress, it may corrupt the data log file.

CONFIGURATION OF USB DISK

In order to configure the data logger session, you should place a device configuration file in the top-level directory of the attached USB Memory Disk. It will be the same format used internally by the Configuration.StoreCurrent() API. The user can construct this file manually or use the Configuration.SaveConfigurationToStorageDevice() method to save the current instrument configuration to the attached USB Memory Disk. These APIs will all take the repeated capability name of a StorageDevice item as an argument, and will act on the file config.json within that device.

REST APIs

digitizer.configuration.store_to_storage_device Writes the current configuration to the specified device.

digitizer.configuration.load_from_storage_device Loads the stored configuration from the specified device.

digitizer.configuration.clear_from_storage_device Clears the stored configuration from the specified device.

digitizer.configuration.get_digest_from_storage_device Retrieves the checksum of the configuration stored in the specified device.

VTEXDigitizer APIs

Configuration.SaveConfigurationToStorageDevice(string) Writes the current configuration to the specified device.

Configuration.LoadConfigurationFromStorageDevice(string) Loads the stored configuration from the specified device.

Configuration.ClearConfigurationFromStorageDevice(string) Clears the stored configuration from the specified device.

Configuration.GetConfigurationDigestFromStorageDevice(string, string&)

Retrieves the checksum of the configuration stored in the specified device.

SAVING DATA TO USB DISK

A new repeated capability has been implemented to the REST API and IVI driver which represents attached storage devices. The data will be saved to any enabled storage devices in HDF5 format. This API allows multiple storage devices to be enabled at the same time, or for VRT and/or DDS streaming to be enabled alongside them. In that case, identical data will be sent to all enabled devices and streaming sockets. FIFO polling via Measurement.Read(), however, will only be supported when all streaming protocols and storage devices are disabled, as the data must be removed from the FIFO to be sent to the storage devices and streaming sockets.

REST APIs

common.storage.devices A collection of attached storage devices.

common.storage.devices.*.enabled Enables logging data to the device.

common.storage.devices.*.num_saved_records The number of records that have been saved to the device since the last measurement was started.

common.storage.devices.*.filename The base filename that the data will be stored as. Supports strftime escape sequences to include the time of measurement.initiate, as well as **%@** for slot name (always inst0 for EX1401), **%N** for a count of measurement.initiate calls since boot, and **%#** for the file index within a single measurement (it is an error to set **file_count != 1** without including this last). Default value is **%@_%Y-%m-%d_%H-%M-%S_%#.h5**.

common.storage.devices.*.file_count The maximum number of files to save data into.

common.storage.devices.*.file_max_records The maximum number of records that will be stored in an individual data file.

common.storage.devices.*.file_rotate Whether or not to overwrite the oldest file when the maximum number of files is reached.

common.storage.devices.*.info Returns a JSON object with information about the device, such as total, used, and available space, volume label, etc. The fields included can be extended when adding new device types or capabilities.

common.storage.devices.*.set_custom_attribute Add a custom attribute (specified as a JSON object) to the top-level attributes in the data file. If the specified attribute name already exists, the value is updated. Custom attributes cannot be added, updated, or removed after the data file is created.

common.storage.devices.*.remove_custom_attribute Remove the attribute with the specified name from the collection of attributes that will be set when the HDF5 data file is created.

common.storage.devices.*.remove_all_custom_attributes Remove all custom attributes from the collection. Calling reset will also clear all custom attributes that have been previously specified.

common.storage.devices.*.custom_attributes A JSON object with all of the attributes that have been specified.

VTEXDigitizer APIs

Storage.Devices A repeated capability container for storage devices attached directly to the instrument.
Storage.Devices.Update() A method that updates the repeated capability container after the driver session is initialized; storage devices that have been removed from the instrument are removed from the collection and newly-attached devices are added.
Storage.Devices.Item.Enabled Enables logging data to the device. Mutually exclusive with **Measurement.Read().**
Storage.Devices.Item.NumSavedRecords The number of records that have been saved to the device since the last measurement was started.
Storage.Devices.Item.Filename The base filename that the data will be stored as.
Storage.Devices.Item.FileCount The maximum number of files to save data into.

Storage.Devices.Item.FileMaxRecords The maximum number of records that will be stored in an individual data file.
Storage.Devices.Item.FileRotate Whether or not to overwrite the oldest file when the maximum number of files is reached.
Storage.Devices.Item.Info Returns a JSON object with information about the device, such as

total, used, and available space, volume label, etc. The fields included can be extended when adding new device types or capabilities.

Storage.Devices.Item.SetCustomAttribute Add a custom attribute to the top-level attributes in the data file. If the specified attribute name already exists, the value is updated. Custom attributes cannot be added, updated, or removed after the data file is created.

Storage.Devices.Item.RemoveCustomAttribute Remove the attribute with the specified name from the collection of attributes that will be set when the HDF5 data file is created.

Storage.Devices.Item.RemoveAllCustomAttributes Remove all custom attributes from the collection. Calling reset will also clear all custom attributes that have been previously specified.

Storage.Devices.Item.GetCustomAttributes A method that returns a JSON object with all of the attributes that have been specified.

In addition to the storage devices repeated capability, the VTEXDigitizer APIs will support the **StreamingData** interface so the driver's disk streaming feature supports the same behavior.

StreamingData.SetCustomAttribute Add a custom attribute to the top-level attributes in the data file. If the specified attribute name already exists, the value is updated. Custom attributes cannot be added, updated, or removed after streaming is enabled.

StreamingData.RemoveCustomAttribute Remove the attribute with the specified name from the collection of attributes that will be set when the HDF5 data file is created.

StreamingData.RemoveAllCustomAttributes Remove all custom attributes from the collection. Calling reset will also clear all custom attributes that have been previously specified.

StreamingData.GetCustomAttributes A method that returns a JSON object with all of the attributes that have been specified.

HDF5 File Hierarchy

HDF5 is a hierarchical file format based on string group names, which contain datasets, which are arrays of like key-value pairs. The root group of the HDF5 file will be "inst0", which is the same as the slot name of the instrument. This will contain one group per channel, named the same as that channel, "CH1" to "CH16", as well as "DIO". Each channel group will contain one dataset for each VRT packet type. HDF5's Packet Table type will be used to pack the raw VRT data into these datasets. Attributes will be set on the "inst0" and channel groups to indicate the instrument's configuration state at the time that the measurement was initiated.

- inst0 (group)
  - <channel> (group)
    - IF_MEAS_INFO (dataset)
      - Packet info - The upper 16 bits of the VRT Header word
      - Packet size - The total number of 32-bit words in the packet
      - Stream ID - The VRT Stream identifier
      - OUI - VTI's IEEE Organizationally Unique Identifier
      - Information class code - The VRT information class identifier
      - Packet class code - The VRT information packet identifier
      - Time seconds - The seconds portion of the packet timestamp
      - Time picoseconds upper - The upper 32 bits of the picoseconds portion of the packet timestamp
      - Time picoseconds lower - The lower 32 bits of the picoseconds portion of the packet timestamp
      - Context Indicator Field - A mask indicating which items are included in Context Fields
      - Context Fields - A list of 32-bit words comprising the data payload of the context packet

- EX_MEAS_INFO (dataset)
  - Packet info - The upper 16 bits of the VRT Header word
  - Packet size - The total number of 32-bit words in the packet
  - Stream ID - The VRT Stream identifier
  - OUI - VTI's IEEE Organizationally Unique Identifier
  - Information class code - The VRT information class identifier
  - Packet class code - The VRT information packet identifier
  - Time seconds - The seconds portion of the packet timestamp
  - Time picoseconds upper - The upper 32 bits of the picoseconds portion of the packet timestamp
  - Time picoseconds lower - The lower 32 bits of the picoseconds portion of the packet timestamp`
  - Context Indicator Field - A mask indicating which items are included in Context Fields
  - Context Fields - A list of 32-bit words comprising the data payload of the context packet
- EX_MEAS_FLOAT32 (dataset)
  - Packet info - The upper 16 bits of the VRT Header word
  - Packet size - The total number of 32-bit words in the packet
  - Stream ID - The VRT Stream identifier
  - OUI - VTI's IEEE Organizationally Unique Identifier
  - Information class code - The VRT information class identifier
  - Packet class code - The VRT information packet identifier
  - Time seconds - The seconds portion of the packet timestamp
  - Time picoseconds upper - The upper 32 bits of the picoseconds portion of the packet timestamp
  - Time picoseconds lower - The lower 32 bits of the picoseconds portion of the packet timestamp
  - Samples - A list of 32-bit floating point data samples
  - Trailer - The 32-bit VRT trailer word
- EX_MEAS_INT32 (dataset)
  - Packet info - The upper 16 bits of the VRT Header word
  - Packet size - The total number of 32-bit words in the packet
  - Stream ID - The VRT Stream identifier
  - OUI - VTI's IEEE Organizationally Unique Identifier
  - Information class code - The VRT information class identifier
  - Packet class code - The VRT information packet identifier
  - Time seconds - The seconds portion of the packet timestamp
  - Time picoseconds upper - The upper 32 bits of the picoseconds portion of the packet timestamp
  - Time picoseconds lower - The lower 32 bits of the picoseconds portion of the packet timestamp
  - Samples - A list of 32-bit integer data samples
  - Trailer - The 32-bit VRT trailer word

SECTION 8

THEORY OF OPERATION

INTRODUCTION

The block diagram in Figure 5-1 illustrates the key components of the analog circuitry. Each of the main blocks is described below.

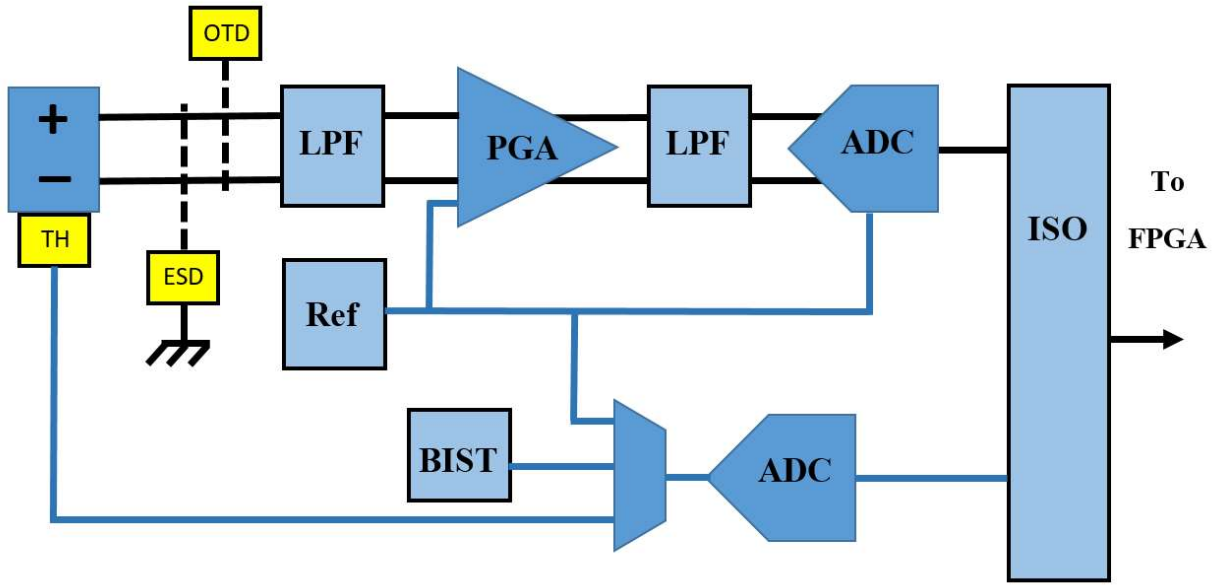


FIGURE 5-1: EX1401 ANALOG CIRCUITRY BLOCK DIAGRAM (PER CHANNEL)

VOLTAGE / THERMOCOUPLE INPUT

Each input channel has a type "U" (universal, copper) miniature thermocouple connector that is used for both temperature and voltage measurement. Each connector has a dedicated thermistor mounted internally for cold junction compensation. Thermal epoxy is used to give low thermal resistance between the thermistor and the copper blades of the mini TC connector. A 1-inch-thick foam barrier is also placed internally, between the mini TC connector and the active electronics. This prevents heat from the active electronics (PGA, ADC, etc.) from skewing the thermistor temperature. This thermal barrier extends from the bottom metal cover to the top metal cover, inside the unit. Ventilation holes are placed near the back of the unit so the exhaust fan does not move air in the thermally stable area of the CJC thermistors.

Each input is protected with ESD clamping circuits that present a small capacitance to earth ground (i.e., the metal enclosure, which is also grounded to your local earth ground by the ground cable included.) There are also gas discharge tubes on both inputs that will arc (short to ground) for any common mode voltage greater than 600V. Each input can have up to +/-500V common mode working voltage with respect to earth ground.

Each input is protected from a sustained, normal mode overvoltage condition, as long as the overvoltage does not exceed +/- 100V between the two inputs of each connector. This is done with a series resistance in each input signal along with clamping diodes. The diodes clamp outside the normal operating range of the PGA and do not disturb the accuracy of the measurement (for normal mode measurements.) When a channel is in overvoltage mode, it can (optionally) be detected by the software and that channel's LED will light.

Each input has open transducer detection. This is particularly useful if a thermocouple connection opens up. This condition can be (optionally) detected by the software and that channel's LED will light. The open transducer detection presents a very small current (typically less than 5nA) into both sides of the mini TC connector inputs. The current will normally flow through the thermocouple wire from the (+) side to the (-) side. As long as the thermocouple wire presents a short circuit (as it normally does) then there is no fault detected. These current sources are small enough not to affect measurement accuracy, but large enough to drive the high-impedance input of the instrumentation amplifier (IA) deterministically into saturation in the event of an open condition. When enabled, they provide continuous monitoring of the input and will generate an open indication event when the open is intermittent in nature. An important feature of the OTD is that the current sources can be enabled or disabled on a per channel basis. This permits the user to choose which of their input signals require open circuit detection.

PROGRAMMABLE GAIN AMPLIFIER

Each channel has its own dedicated analog signal conditioning chain as well as a dedicated ADC, reference, and BIST circuit.

There are two low pass filters in the chain, one prior to the programmable gain amplifier (PGA) and one prior to the ADC. Both are single pole filters with a nominal 3dB cutoff at 30kHz. These two filters, along with a filter in the PGA section, provide the Nyquist frequency rejection for the ADC. These analog filters keep anti-aliasing of high frequency to a minimum so the digital data output of the ADC can then be confidently filtered by the subsequent digital filters inside the FPGA.

The PGA amplifies the input differential signal and outputs a differential signal to the subsequent LPF. The ADC then converts the differential signal to digital sampled data. The PGA provides excellent common mode rejection (typically -130dB at 50/60Hz and -120dB at 1kHz). PGAs have the tendency to shift their dc offset in the presence of very high frequency signals. This effect would be particularly problematic, as the filters that follow the PGA would not attenuate it. However, the presence of the differential and common mode filter preceding the PGA attenuates high frequency interference before it reaches the PGA. This decreases the possibility of dc rectification and provides the system with excellent CMRR characteristics at all frequencies.

The PGA operates with +/- 13V supplies (each channel has its own isolated power supply and the PGA has excellent power supply rejection of 120dB typical.) The +/- 13V supplies allow a native +/-10V input range without the need for resistor dividers.

ANALOG TO DIGITAL CONVERSION

Each channel has its own, dedicated ADC that samples the analog signal at some rate between 320kSPS and 640kSPS (depending upon customer selected sample rate.) The ADC is a successive approximation with register (SAR) type converter. The ADC oversamples the analog input signal by a factor of 32 and then performs digital filtering (linear phase response) to eliminate out of band noise. The ADC generates 24-bit samples at the reduced output data rate of 10kSPS to 20kSPS. Therefore, the effective analog sample rate is somewhere between 10kSPS and 20kSPS, depending upon customer selected sample rate. The ADC has excellent AC and DC characteristics that allow the EX1401 to perform more than just thermocouple measurements. The AC response, along with the analog and digital filtering allow applications beyond thermocouples.

Each ADC has its own, dedicated 2.5V reference. The reference has a long term stability of 50ppm over the first 1000 hours and a typical temperature coefficient of 2 ppm/C. The reference can be

measured by the ADC via the PGA or it can be independently measured by the built-in-self-test circuit. The value of the references are reported in the BIST report.

All channels on the EX1401 are totally independent, but are synchronized by the same clock. Therefore, all ADCs in the system sample their analog inputs at the same time and generate output data at the same rate.

BUILT IN SELF TEST AND CJC MEASUREMENT

Each channel has its own, dedicated built-in-self-test circuit which includes a separate ADC from the measurement path. The BIST ADC operates at a slower rate, 50 to 100 Samples/Sec depending upon customer selected sample rate. This lower sample rate provides the high accuracy needed for CJC measurement and reference measurement.

The BIST ADC is responsible for measuring the output of the thermistor used for CJC. The thermistor is part of a resistor divider circuit driven by the on board reference. The BIST ADC can measure both the reference and the thermistor output so only a ratio metric calculation needs to be done to find the thermistor resistance. Calculation of the junction temperature is then done digitally in the FPGA based on the coefficients of the thermistor used (US Sensor PS103J2). The BIST ADC cycles through all measurements continuously which reduces the CJC measurement rate to 10 SPS to 20 SPS (depending upon customer selected sample rate.)

The BIST ADC also measures the temperature of each channel's active electronics. This is done separately from the CJC measurement, it is not using the thermistor. The temperature of the active electronics is on the other side of the thermal barrier from the CJC thermistor. The temperature is reported for every channel, as part of the BIST report.

The BIST ADC also measures various power supplies on each analog channel and these are also part of the BIST report.

ISOLATION BARRIER

Each channel has its own, isolated power supply. The isolated power supply takes the bulk 5V output power from the PoE+ power supply and develops the isolated power supplies (+13V, -13V, 3.3V) needed by the PGA, ADC and BIST circuits. The isolator for both power and digital communications gives galvanic isolation between the two sides. Maximum continuous working voltage across the isolation barrier is 500Vpeak. The isolation barrier is designed to conform with IEC61010-1 (3rd edition) for: pollution degree 2, altitude < 5000m, overvoltage category II.

THERMOCOUPLE CALCULATIONS

There are two thermocouple type-specific calculations that are performed in the EX1401. The first calculation transforms the CJC temperature into a compensating voltage that is mathematically added to the measured input voltage. The second calculation transforms this total voltage into its final thermocouple temperature. For maximum accuracy, both of these calculations are performed using the full-order polynomial equations and coefficients from the NIST ITS-90 Thermocouple Database, not from lookup tables or piecewise linear approximations.

SECTION 9

EX1401 CALIBRATION

INTRODUCTION

It is recommended that the EX1401 have factory calibration performed annually to ensure that the instrument maintains its accuracy and precision. The following procedure describes the resources and steps necessary to perform factory calibration and is valid for the following assemblies:

70-0355-100: EX1401, 48-Ch Voltage Input Instrument
70-0355-200: EX1016A, 32-Ch Voltage, 16-Ch TC Input Instrument
70-0355-300: EX1401, 16-Ch Voltage, 32-Ch TC Input Instrument
70-0355-400: EX1401, 48-Ch TC Input Instrument
70-0355-500: EX1401-TC, 48-Ch Voltage Input Instrument with TC Connectors
70-0536-000: EX1401, 32-Ch Thermocouple/Voltage Instrument

REQUIRED RESOURCES

Equipment Needed

LAN/GPIB Gateway (Agilent E5810A recommended)
DMM (either an Agilent 3458A or Keithley 2002)
Test leads with banana jacks
One Ethernet switch
Three Ethernet cables (straight cables)
One GPIB cable

Software Needed

A web browser (Internet Explorer, Firefox, etc.)
The latest version of EX1401 firmware, available on the VTI Instruments web site.
(The latest version of RX10xx firmware, available on the VTI Instruments web site).
Bonjour (optional: used to discover the EX1401/RX10xx, requires use of IE Version 6 or higher)
Agilent Connection Expert (optional: used for instrument discovery if Bonjour is not used)
Any NFS Server software (optional: used to collect the calibration log and data)

SECTION 11

ONBOARD MEMORY

ONBOARD MEMORY AND CLEARING PROCEDURE

The EX1401 family of instruments contains onboard memory which stores various information about the unit as well as data acquired. details the memory components and provided a procedure for clearing the memory.

Component	Volatile?	Contains	User Writeable?	Clear Procedure
2x32 MB Flash (MFG: Spansion P/N: S25FL256SAGNFI000)	No	Firmware	No	None
		File System	No	None
		Stored Instrument Configuration	Yes	Go to webpage, navigate to the **Nonvolatile Memory** page, check the **config** checkbox and press the Submit button.
		Network Configuration	Yes	
		Time Configuration	Yes	
2x512 MB DDR3 SDRAM (MFG: Micron Tech P/N: MT41K256M16HA-125 AAT:E)	Yes	Runtime Data	Yes	Power cycle machine
64KB FEEPROM (MFG: Atmel P/N: AT24C512C-XHM-T)	No	Main board model and serial number	No	None
		Main board factory full calibration	No	None
		Main board user full calibration	Yes	Go to webpage, navigate to the **Nonvolatile Memory** page, check the **main_full_cal** checkbox and press the Submit button.
64KB FEEPROM (MFG: Atmel P/N: AT24C512C-XHM-T)	No	Mezzanine board model and serial number	No	None
		Mezzanine board factory full calibration	No	None
		Mezzanine board user full calibration	Yes	Go to webpage, navigate to the **Nonvolatile Memory** page, check the **mezz_full_cal** checkbox and press the Submit button.

TABLE 7-1: ONBOARD MEMORY AND CLEARING PROCESS

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