AXN/TDC/401

Thermocouple ADC (cold junction compensation, 3.125 kHz b/w) - 15ch at 12.5 ksps

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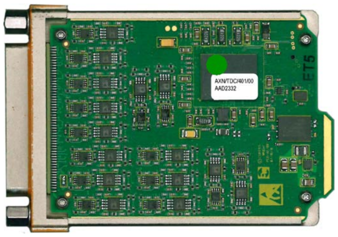

Key Features

- 15 grounded or isolated thermocouple input channels
- Three PT50/PT100 channels and one built-in top-block sensor for junction compensation
- Supports multiple thermocouple types with digital cold junction compensation and programmable thermocouple type per channel
- Accuracy (0.5°C typical for K-type in -50 to 150°C range, 1°C typical outside this range)
- 16-bit simultaneous sampling with three configurable output streams on each channel
- User defined linearization and compensation for errors in the entire measurement chain
- Open thermocouple detection

Applications

- Thermocouple temperature measurements

Overview

The AXN/TDC/401 is used to condition and digitize up to fifteen analog thermocouple channels, three 4-wire RTD (dedicated for PT100) channels and offers top-block built-in temperature sensor.

The AXN/TDC/401 performs linearization for the selected cold junction sensor and thermocouple, and compensates the thermocouple channel accordingly. Any of the three PT50/PT100 channels or top-block built-in temperature sensor can be selected as cold junction compensation.

The module offers programmable pull-down resistors for thermocouples isolated from the module ground.

At the heart of the AXN/TDC/401 is a hard-wired state-machine that oversamples all channels at a rate between 50 ksps and 100 ksps and digitally filters any noise above the user-programmable cutoff frequency. This is achieved using cascaded, 15-tap FIR filters with output rate decimation, followed by a final FIR or IIR filter. If IIR filtering mode is selected, the last digital filter in the filtering chain is an 8th or 16th order (selectable) Butterworth filter. If FIR mode is selected, the last digital filter in the filtering chain is a 49-tap Kaiser window, Beta 6 filter.

There are three independently configurable output streams per channel, allowing different sample rate, cutoff, and filter type to be selected for each output stream.

All signals are sampled simultaneously. When several channels are sampled at different sampling rates, at the start of an acquisition cycle all channels are aligned.

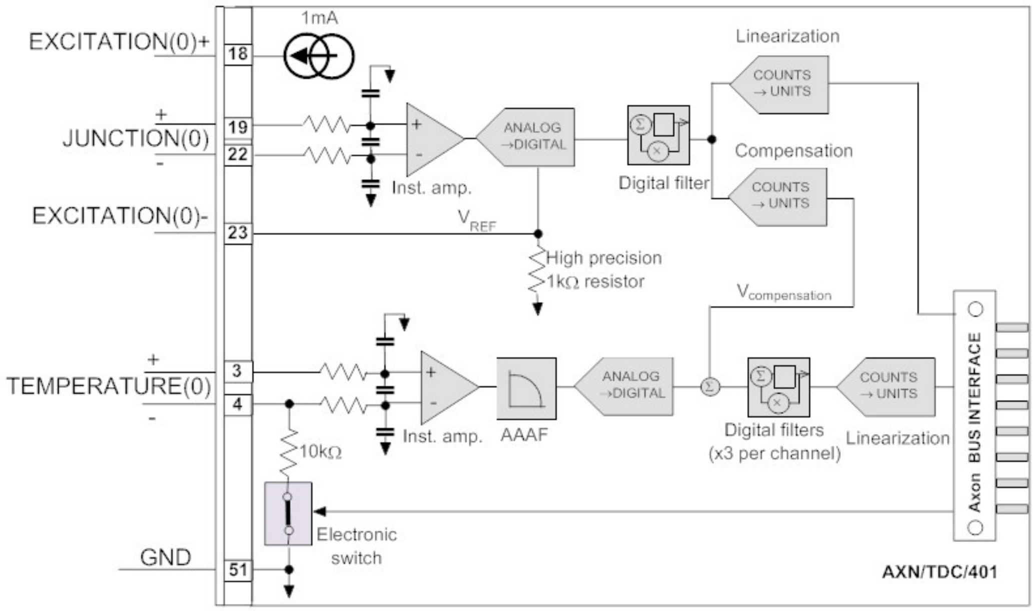

Figure 1: First of fifteen channels configured for isolated thermocouple

Specifications

All values provided in the following specification tables are valid within the operating temperature range specified under "Environmental ratings" in the "General specifications" table.

TABLE 1	General specifications				
PARAMETER	MIN.	TYP.	MAX.	UNITS	CONDITION/DETAILS
Slots	–	–	1	–	Can be placed in any user-slot in any combination.
Mass					
	–	50	–	g	
	–	1.76	–	oz	Design metric is grams.
Height above chassis					For recommended clearance requirements see the *CON/KAD/002/CP* data sheet.
bare connector	–	–	11	mm	
bare connector	–	–	0.43	in.	Design metric is millimeters.
Power consumption					
+15V		155	175	mA	Includes current used for Excitation(x) outputs. No inputs left floating. See "Unused inputs" on page 20.
total power		2.33	2.63	W	Particular combinations of Axon chassis and modules may have power limitations. For details, contact Curtiss-Wright support (acra-support@curtisswright.com).
Environmental ratings					See *Environmental Qualification Handbook for Axon Products*.
operating temperature	-40	–	85	°C	Chassis base/side plate temperature.
storage temperature	-55	–	125	°C	

TABLE 2	Thermocouple inputs				
PARAMETER	MIN.	TYP.	MAX.	UNITS	CONDITION/DETAILS
Inputs	–	–	15	–	With threes independently configurable output streams per channel.
Sampling rate					While the sampling rate can be set individually, each must have a power of two times any other (¼, ½ ...2, 4).
Temperature[14:0]	0.5	–	12,500	sps	These parameters relate to TEMPERATURE(x) ± inputs.
Primary sampling frequency	50	–	100	ksps	The primary sampling frequency (f_p) is set up to be the power of two of each output sample frequency. It is greater than the minimum specified value and lower or equal to the maximum specified value.
Input temperature					The input temperature range is limited by the input voltage range of ±100 mV and depends on the specific thermocouple type and the required cold junction temperature range. Where applicable, limits for specific thermocouple types are defined in the following Condition/Details column.
full scale range K-type thermocouple	-270	–	1,372	°C	For accuracy figures within a -150˚C and 1100˚C range, refer to the DC error parameter rows in this table.
full scale range B-type thermocouple	40	–	1,820	°C	When using this thermocouple type, there is a limitation on the minimum cold junction temperature. This must be guaranteed during measurement.

TABLE 2	Thermocouple inputs (continued)				
PARAMETER	MIN.	TYP.	MAX.	UNITS	CONDITION/DETAILS
full scale range C-type thermocouple	0	–	2,315	°C	When using this thermocouple type, there is a limitation on the minimum cold junction temperature. This must be guaranteed during measurement.
full scale range J-type thermocouple	-210	–	1,200	°C	
full scale range E-type thermocouple	-270	–	1,000	°C	
full scale range N-type thermocouple	-265	–	1,300	°C	
full scale range R-type thermocouple	-50	–	1,767	°C	When using this thermocouple type, there is a limitation on the minimum cold junction temperature. This must be guaranteed during measurement.
full scale range S-type thermocouple	-50	–	1,767	°C	When using this thermocouple type, there is a limitation on the minimum cold junction temperature. This must be guaranteed during measurement.
full scale range T-type thermocouple	-270	–	400	°C	
full scale range T99-type thermocouple	-59	–	229	°C	
full scale range XK_L-type thermocouple	-200	–	800	°C	For accuracy figures within a -150˚C and 800˚C range, refer to the DC error parameter rows in this table.
Input voltage					Differential ended voltage across the TEMPERATURE(x)± inputs.
operating range	-100	–	100	mV	
overvoltage protection	-40	–	40	V	Voltages outside of this range can damage input.
DC error when using ACD/CJB/003 cold junction block for compensations					For a grounded or isolated K-type and XK_L-type thermocouple. This error includes the cold junction measurement error, and is met for an ambient temperature change rate of up to 1°C per minute. Many other thermocouple types are supported (see “Accuracy” on page 14).
error	–	0.5	1.5	°C	For measured temperatures of -50°C to 150°C.
error	–	1.0	2.5	°C	For measured temperatures outside -50°C to 150°C and bigger than -150°C.
DC error when using top-block built-in temperature sensor for compensation					For a grounded or isolated K-type and XK_L-type thermocouple. This error includes the cold junction measurement error, and is met for an ambient temperature change rate of up to 1°C per minute. (A backshell such as an ACD/BAC/002 must be used to achieve this accuracy.) Many other thermocouple types are supported (see “Accuracy” on page 14).
error	–	1.3	2.5	°C	For measured temperatures of -50°C to 150°C.
error	–	1.8	3.5	°C	For measured temperatures outside -50°C to 150°C and bigger than -150°C.
AC gain error					Gp = 1, f_s = 12.5 ksps, $f_c = f_s / 4$ ((f_c : filter cutoff frequency; f_s : sampling frequency). Includes digital filter amplitude characteristics.
for 0 Hz < f_{in} ≤ 250 Hz	–	0.025	0.1	%	(f_{in} : input signal frequency)

TABLE 2	Thermocouple inputs (continued)				
PARAMETER	MIN.	TYP.	MAX.	UNITS	CONDITION/DETAILS
for 250 Hz < f_{in} ≤ 1 kHz	–	0.15	0.3	%	
for 1 kHz < f_{in} ≤ 2 kHz	–	0.6	1.2	%	
Effective number of bits					
f_c ≤ 250 Hz	12	13.5	–	bits	
f_c > 250 Hz	11	12.5	–	bits	
Crosstalk	–	-100	-80	dB	TEMPERATURE(x)±. Typical value claimed at 250 Hz and below.
Common mode					For TEMPERATURE(x)±.
voltage range	-5	–	5	V	Operational voltage range. Single ended voltages on individual TEMPERATURE(x)± pins must also fit into this range.
rejection ratio	80	100	–	dB	Applies within the above common mode voltage range. Claimed for frequencies up to 500 Hz.
rejection ratio	74	80	–	dB	Applies within the above common mode voltage range. Claimed for frequencies above 500 Hz.
Analog filter					Analog filters are Butterworth.
Anti aliasing filter					
poles	–	–	4	–	
filter cutoff -3 dB	6.2	6.6	6.9	kHz	
Digital filter					For IIR8 setting of Filter Mode, digital filter is Butterworth with output sample stream decimated by 2, 4, 8, 16, 32, 64 or 128.
poles	–	–	8	–	
filter cutoff (f_c) -3 dB	0.1	–	16	f_s	The maximum value is limited to 3.125 kHz. See Filter Cutoff settings in the Instrument settings table on page 8.
0.1 dB bandwidth	–	0.8	–	f_c	
aliasing to 0.1 dB band	–	–	-75	dB	Meets specification for Filter Cutoff settings lower than or equal to 1/4.
aliasing to f_c	–	–	-75	dB	Meets specification for Filter Cutoff settings lower than or equal to 1/4.
Filter delay	1.99	2.0	2.01	ms	Measured for $f_{in} = f_c = f_s / 4 = 1$ kHz.
Digital filter					For IIR16 setting of Filter Mode, digital filter is Butterworth with output sample stream decimated by 2, 4, 8, 16, 32, 64 or 128.
poles	–	–	16	–	
filter cutoff (f_c) -3 dB	0.1	–	16	f_s	The maximum value is limited to 3.125 kHz. See Filter Cutoff settings in the Instrument settings table on page 8.
0.1 dB bandwidth	–	0.9	–	f_c	
aliasing to 0.1 dB band	–	–	-75	dB	Meets specification for Filter Cutoff settings lower than or equal to 1/4.
aliasing to f_c	–	–	-75	dB	Meets specification for Filter Cutoff settings lower than or equal to 1/4.
Filter delay	2.99	3.0	3.01	ms	Measured for $f_{in} = f_c = f_s / 4 = 1$ kHz.

TABLE 2	Thermocouple inputs (continued)				
PARAMETER	MIN.	TYP.	MAX.	UNITS	CONDITION/DETAILS
Digital filter					For FIR setting of Filter Mode, digital filter is 49-tap Kaiser window, Beta 6 FIR filter with output sample stream decimated by 2.
poles	–	–	–	–	
filter cutoff (f_c) -6 dB	0.1	–	16	f_s	The maximum value is limited to 3.125 kHz. See Filter Cutoff settings in the Instrument settings table on page 8.
0.1 dB bandwidth	–	0.32	–	f_c	Specified value is for $f_c = f_s / 10$ filter.
0.1 dB bandwidth	–	0.46	–	f_c	Specified value is for $f_c = f_s / 8$ filter.
0.1 dB bandwidth	–	0.59	–	f_c	Specified value is for $f_c = f_s / 6$ filter.
0.1 dB bandwidth	–	0.66	–	f_c	Specified value is for $f_c = f_s / 5$ filter.
0.1 dB bandwidth	–	0.72	–	f_c	Specified value is for $f_c = f_s / 4$ or equal or greater than $f_s / 2$ filters.
0.1 dB bandwidth	–	0.79	–	f_c	Specified value is for $f_c = f_s / 3$ filter.
0.1 dB bandwidth	–	0.83	–	f_c	Specified value is for $f_c = f_s / 2.5$ filter.
aliasing to 0.1 dB band	–	–	-75	dB	Meets specification for Filter Cutoff settings lower than 1/4.
aliasing to f_c	–	–	-75	dB	Meets specification for Filter Cutoff settings lower than 1/4.
Filter delay	3.99	4.0	4.01	ms	Measured for $f_{in} = f_c = f_s / 4 = 1$ kHz.
Input resistance					
between inputs	10	–	–	MΩ	Module powered on and measured between TEMPERATURE(x)+ and TEMPERATURE(x)-.
between inputs	10	–	–	kΩ	Module powered off and measured between TEMPERATURE(x)+ and TEMPERATURE(x)-.
single ended input to GND	10	–	–	MΩ	Module powered on and measured at TEMPERATURE(x)+ or TEMPERATURE(x)-.
single ended input to GND	10	–	–	kΩ	Module powered off and measured at TEMPERATURE(x)+ or TEMPERATURE(x)-.
Pull-down resistor					Pull-down resistor can be enabled or disabled between TEMPERATURE(x)- and GND.
resistance	–	10	–	kΩ	Nominal resistance of pull-down resistor.
error	–	0.5	–	%	Initial resistor tolerance.
Open circuit detection resistor					Two open circuit detection resistors are populated between TEMPERATURE(x)± and the module supply rails, in such a way that inputs are pulled in opposite directions; where this results in an open circuit, the channel is put on the positive rail. As well as the channel reading its most positive value, this state is indicated by the ThermocoupleOpen parameter.
resistance	–	50	–	MΩ	Nominal resistance of pull up/down resistors.
error	–	5	–	%	Initial resistor tolerance.

TABLE 3	Cold junction inputs				
PARAMETER	MIN.	TYP.	MAX.	UNITS	CONDITION/DETAILS
Inputs	–	–	3	–	For RTD types of sensors (recommended PT100). RTD sensors connected to cold junction channels are supplied from 1 mA current source (typical value) from EXCITATION(x)± ports. The measurement is ratiometric, compared with the embedded, high precision 1 kΩ resistor.
Sampling rate					While the sampling rate can be set individually, each must have a power of two times any other (¼, ½ ...2, 4).
JunctionTemperature[2:0]	0.5	–	12,500	sps	These parameters relate to JUNCTION(x)± inputs.
Primary sampling frequency	4	–	8	sps	The primary sampling frequency (f_p) is set up to be the power of two in relation to the primary sampling frequency defined for thermocouple channels. In case JunctionTemperature is output at a higher rate, the sample is repeated.
Input voltage					Differential ended voltage across the JUNCTION(x)± inputs.
operating range	0	–	250	mV	This measurement is a ratiometric resistance measurement performed with 1 mA (typical) excitation current. The maximum value claimed here limits the possible maximum temperature measured for sensors with higher resistances than PT100 RTDs (such as PT200).
overvoltage protection	-40	–	40	V	Voltages outside of this range can damage input.
Input temperature					
Full scale range	-200	–	400	°C	Equivalent temperatures for RTD sensor.
DC error	–	0.1	0.3	°C	Defined for PT100 sensor and range set to -55 to 125°C.
Effective number of bits	–	13.5	–	bits	$f_{in} \leq 4$ Hz (f_{in} : input signal frequency).
Crosstalk	–	-100	-80	dB	$f_{in} \leq 4$ Hz
Analog filter					Analog filter is Butterworth.
poles	–	–	1	–	
filter cutoff -3 dB	–	35	–	kHz	
Digital filter					Digital filter is embedded in the A/D converter. See “Signal filtering on cold junction channels” on page 19.
filter cutoff (f_c) -3 dB	–	4	–	Hz	
0.1 dB bandwidth	–	0.1	–	f_c	(f_c : filter cutoff frequency)

TABLE 4	Top-block built-in temperature sensor				
PARAMETER	MIN.	TYP.	MAX.	UNITS	CONDITION/DETAILS
Inputs (Top-block Temperature)	–	–	1	–	From sensor provided within top-block.
Input temperature					
full scale range	-55	–	125	°C	
DC error	–	0.5	1.0	°C	Sensor manufacturer specification.

TABLE 5	On board PCB temperature sensor				
PARAMETER	MIN.	TYP.	MAX.	UNITS	CONDITION/DETAILS
Inputs (ModuleTemperature)	–	–	1	–	From sensor provided on module PCB.
Input temperature					
full scale range	-55	–	125	°C	
DC error	–	0.5	1.0	°C	Sensor manufacturer specification.

Setting up the AXN/TDC/401

All module setup can be defined in XML using XidML® schemas (see http://www.xidml.org).

Instrument settings

SETUP DATA	CHOICE	DEFAULT	NOTES
Manufacturer	-	-	-
Name	ACRA CONTROL	ACRA CONTROL	Name of manufacturer.
PartReference	AXN/TDC/401	AXN/TDC/401	The instrument part reference.
SerialNumber	AAA1234	AAA1234	Unique name for each module.
Channels	-	-	-
Temperature(14:0) Analog Input	-	-	-
Settings	-	-	-
Filter Mode(0)	FIR IIR8 IIR16	FIR	Specifies the filter mode for a specific channel of the 1st parameter. FIR is Kaiser window Beta = 6, 49-tap FIR filter; IIR8 is 8th order Butterworth IIR filter; and IIR16 is 16th order Butterworth IIR filter.
Filter Mode(1)	FIR IIR8 IIR16	FIR	Specifies the filter mode for a specific channel of the 2nd parameter. FIR is Kaiser window Beta = 6, 49-tap FIR filter; IIR8 is 8th order Butterworth IIR filter; and IIR16 is 16th order Butterworth IIR filter.
Filter Mode(2)	FIR IIR8 IIR16	FIR	Specifies the filter mode for a specific channel of the 3rd parameter. FIR is Kaiser window Beta = 6, 49-tap FIR filter; IIR8 is 8th order Butterworth IIR filter; and IIR16 is 16th order Butterworth IIR filter.
Filter Cutoff(0)	1/4 1/2 1 2 4 8 16 1/10 1/8 1/6 1/5 1/3 1/2.5	1/4	Required cutoff point for the filter is the chosen value referenced to the user sampling frequency. Setting for 1st channel parameter.

SETUP DATA	CHOICE	DEFAULT	NOTES
Filter Cutoff(1)	1/4 1/2 1 2 4 8 16 1/10 1/8 1/6 1/5 1/3 1/2.5	1/4	Required cutoff point for the filter is the chosen value referenced to the user sampling frequency. Setting for 2nd channel parameter.
Filter Cutoff(2)	1/4 1/2 1 2 4 8 16 1/10 1/8 1/6 1/5 1/3 1/2.5	1/4	Required cutoff point for the filter is the chosen value referenced to the user sampling frequency. Setting for 3rd channel parameter.
Linearization URL	UTF-8 String	.\LookupFiles\ Thermocouple\TYPEK.LU	Specifies the URL to the linearization lookup file.
Junction Compensation Channel	No compensation Junction temperature 0 Junction temperature 1 Junction temperature 2 Top-block sensor	Top-block sensor	It defines which channel is used as cold junction compensation.
User Compensation URL	UTF-8 String		Specifies the URL to the user compensation file.

SETUP DATA	CHOICE	DEFAULT	NOTES
User Compensation Channel	No compensation Channel independent Channel 0 Channel 1 Channel 2 Channel 3 Channel 4 Channel 5 Channel 6 Channel 7 Channel 8 Channel 9 Channel 10 Channel 11 Channel 12 Channel 13 Channel 14 Channel 15 Junction temperature 0 Junction temperature 1 Junction temperature 2 Top-block temperature sensor Module temperature sensor	No compensation	This setting defines which channel is used as the compensation channel for the linear user calibration.
Pull-down Resistor	Disabled Enabled	Enabled	Specifies if the switch connecting the pull-down resistor is to be enabled between TEMPERATURE(x)- and GND nets.
JunctionTemperature(2:0) Analog Input	-	-	-
Settings	-	-	-
Linearization URL	UTF-8 String	.\LookupFiles\RTD\PT100_385.LU	Specifies a URL to linearization lookup file.
User Compensation URL	UTF-8 String		Specifies a URL to user compensation file.
User Compensation Channel	No compensation Channel independent Top-block temperature sensor Module temperature sensor	No compensation	This setting defines which channel is used as compensation channel for linear user calibration.

Parameter definitions

NAME/DESCRIPTION	BASE UNIT	DATA FORMAT	BITS	REGISTER DEFINITION
Global Parameters				
Top-blockTemperature Top-block temperature signal data.	Celsius	OffsetBinary	16	R[15:0]
ModuleTemperature Module temperature signal data.	Celsius	OffsetBinary	16	R[15:0]
ThermocoupleOpen Thermocouple open-circuit status register.	BitVector	BitVector	16	R[15:0] R(15) Reserved for future use. R[14:0] ThermocoupleOpen status indicated with one bit per channel as follows: 0 - No open thermocouple circuit. 1 - Open thermocouple circuit detected. Note: Temperature(0) channel related information is at LSB position.
ReadCounter Incrementing counter for debug usage.	Count	OffsetBinary	16	R[15:0]
Report Report status of module.	BitVector	BitVector	16	R[15:0] R(15) ModuleTemperature sensor not responding. R(14) Top-blockTemperature sensor not responding. R[13:11] Reserved for future use. R(10) ADC for JunctionTemperature(2) not responding. R(9) ADC for JunctionTemperature(1) not responding. R(8) ADC for JunctionTemperature(0) not responding. R[7:2] Reserved for future use. R(1) ADC for Temperature[14:8] not responding. R(0) ADC for Temperature[7:0] not responding.
Temperature(14:0)(2:0) Parameters				
Temperature(14:0)(2:0) Temperature signal data.	Celsius	OffsetBinary	16	R[15:0]
JunctionTemperature(2:0) Parameters				
JunctionTemperature Junction temperature signal data.	Celsius	OffsetBinary	16	R[15:0]

Configurable parameters

Temperature(14:0)(2:0)

SETUP DATA	CHOICE	DEFAULT	NOTES
Range Maximum	-270 to 2315	1372	Range maximum for thermocouple channel.
Range Minimum	-270 to 2315	-270	Range minimum for thermocouple channel.

JunctionTemperature(2:0)

SETUP DATA	CHOICE	DEFAULT	NOTES
Range Maximum	-200 to 400	125	Range maximum for RTD cold junction channel.
Range Minimum	-200 to 400	-55	Range minimum for RTD cold junction channel.

NOTE: It is recommended that names do not contain any of the following five characters "/><\.

Getting the most from the AXN/TDC/401

Wiring configurations

The following two figures show possible wiring configurations for the AXN/TDC/401.

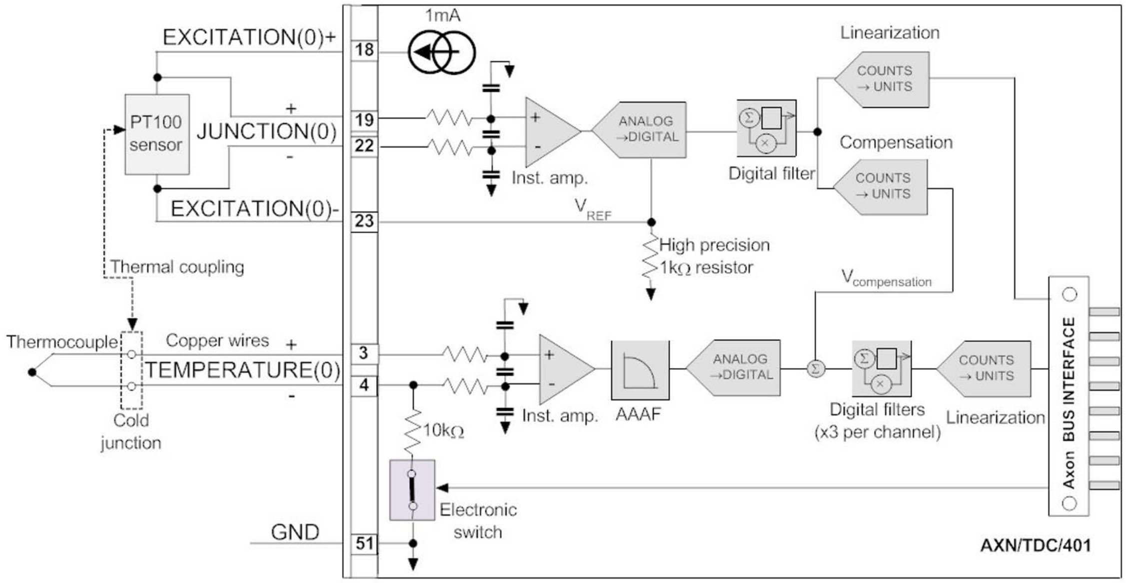

Figure 2: First thermocouple channel configured for isolated thermocouple (pull-down resistor on the module enabled) with external cold junction and first cold junction channel connecting to PT100 sensor

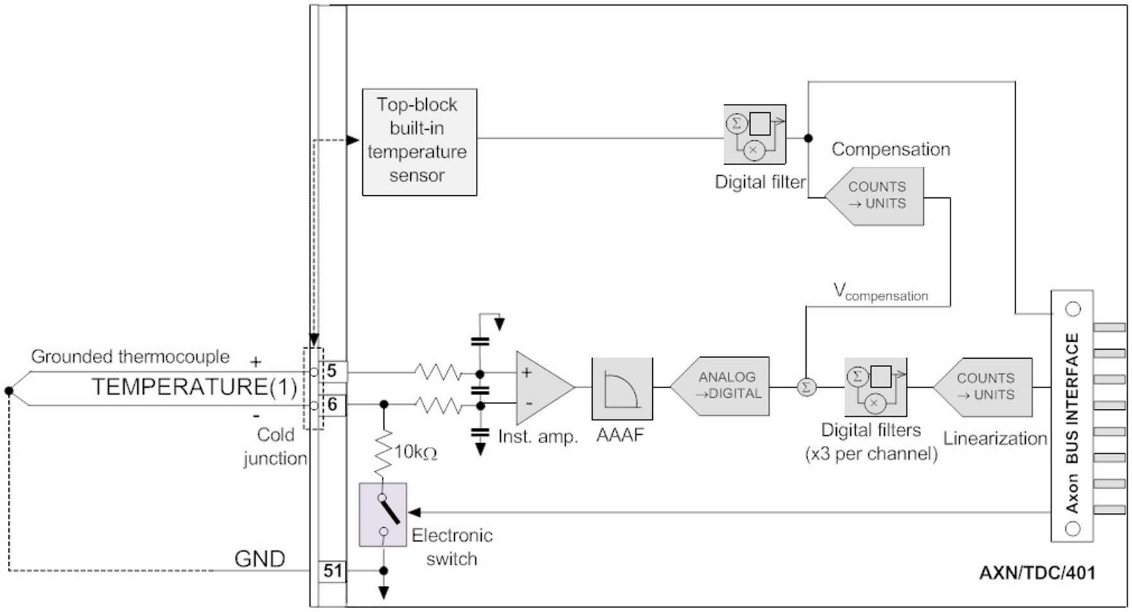

Figure 3: Second thermocouple channel configured for grounded thermocouple with cold junction at top-block connector and taken from top-block built-in temperature sensor

Bias current return path

If the signal source is isolated with respect to the Axon (isolated thermocouple case), a common-mode resistance between one of the inputs and ground (GND) must be used to provide a return for bias currents, and reduce common-mode noise pick-up. Bias currents are in the order of nAs. To correctly set up the return path for bias currents, either internal pull-down resistors must be enabled to internally pull-down to GND or an external path to GND must be used, for example short (0Ω) to GND. Figure 2 on page 13 shows the internal pull-down resistor switch enabled, which provides a return path for the bias current.

NOTE: To enable the internal pull-down resistor, the Pull-down Resistor must be set to Enabled.
For grounded thermocouples, the Pull-down Resistor should be set to Disabled.

Accuracy

The accuracy of the AXN/TDC/401 is specified for K-type thermocouples over the range specified in the DC error parameter rows in Table 2 on page 2. It is also met for J, XK_L, and E-type thermocouples that have a similar sensitivity. For thermocouples with a lower sensitivity (R, S, and T-type), the accuracy figure can be estimated by scaling the accuracy claimed for a K-type thermocouple by the ratio of its sensitivity (K-type thermocouple), to the sensitivity of the considered thermocouple.

A similar effect on accuracy occurs in very nonlinear ranges of thermocouple characteristics, where sensitivity of thermocouples drop (for example, below -150°C for K-type thermocouples).

C-type thermocouples are not specified below 0°C. B-type thermocouples do not have monotonic function below approx. 20°C, and have extremely low sensitivity below 40°C. If a B-type or C-type thermocouple is used and cold junction operates below 0°C (for B-type) and 35°C (C-type), the reading from the related thermocouple channel will be invalid.

R and S-type thermocouples are not specified below -50°C, therefore, if used and cold junction operates below this temperature, the reading from the related thermocouple channel will be invalid.

Configuring the module

Thermocouple channels have thermocouple linearization and cold junction compensation applied to all readings. The channel's Junction Compensation Channel setting indicates which channel is used to measure the cold junction temperature. There are two possible sources for compensation: using one of three RTD cold junction channels; or using the built-in top-block temperature sensor. An alternative is to use no compensation, in which case it is assumed that cold junction compensation is done externally, whereby only thermocouple linearization is required.

Using cold junction channels for compensation

An example of such a case is presented in Figure 2 on page 13 where thermocouple channel 0 uses cold junction channel 0 as a compensation channel. In order to set this up in DAS Studio 3 software, the Junction Compensation Channel setting for the thermocouple channel 0 must be pointing to the selected cold junction channel (Junction temperature 0). The cold junction channel Linearization setting must be configured to select the relevant RTD sensor linearization lookup file.

Three RTD cold junction channels allows may use external cold junction blocks, which are remote to the module, and then connect thermocouple nets to the module using copper wires. Supported RTD sensors are those which at 1 mA excitation current, generate a voltage within the 0V – 0.25V range covering all cold junction temperature ranges selected by the user.

PT50 and PT100 sensors support the specified temperature range of the cold junction channel, where PT200 sensors apply limits to the maximum cold junction range to accommodate the RTD cold junction channel voltage range.

Based on testing with the ACD/CJB/003 (cold junction block), the lowest thermocouple measurement errors are achieved when the Junction temperature 0 channel is selected to compensate for thermocouple channels 0, 12, and 14; the Junction temperature 1 channel is selected to compensate for thermocouple channels 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11; and the Junction temperature 2 channel is selected for thermocouple channel 13.

Using the built-in top-block temperature sensor for compensation

When thermocouple channel's Junction Compensation Channel setting is set to Top-block sensor, then the built-in top-block temperature sensor is used as the source for junction compensation. The advantage of this mode is that it provides a simple solution for cases where thermocouples are lead directly to the top-block. However, the disadvantage is that it is a less accurate solution than discussed in the previous paragraph. Example of such setup is presented in Figure 3 on page 13.

ThermocoupleOpen parameter

This parameter indicates the input open-circuit status. Module differential ended inputs are pulled via weak resistors to input stage supply rails, in a way that if there is an open circuit on any line, the instrumentation amplifier output will be at a positive rail. This state is detected and indicated in the ThermocoupleOpen parameter with one bit per channel as follows:

0 – No open circuit detected

1 – Open circuit detected

NOTE: Temperature(0) status is on the LSB position; bit 15 is reserved for future use.

Digital filters overview (Temperature channels)

The AXN/TDC/401 samples all channels simultaneously at a high rate, which is defined in the f_p range in the Table 2 on page 2. Sample values are scaled by various blocks (such as internal calibration, user compensation, junction compensation, and user range) and then passed into the digital filter and decimation blocks. These scaled samples pass through a cascade of digital anti-aliasing filters and decimations, which are there to lower the sample rate to the last user-selected filter, while maintaining aliasing at a negligible level. Then, depending on the Filter Mode and Filter Cutoff settings chosen, the sample passes through the final user-selected filter and decimator.

The AXN/TDC/401 offers three types of final filters:

- FIR
- IIR8
- IIR16

Using the Filter Mode setting, each can be individually selected per channel and/or stream.

The FIR filter is a 49-tap Kaiser window Beta 6 filter. The advantage of this filter is constant filter delay versus input signal frequency, which facilitates time correlation of various signals in post-processing and visualization, and guarantees lack of phase distortions for non-sinusoidal input signals. The disadvantage is it has less flat passband, which gets narrower versus f_c for lower f_c settings.

IIR8 and IIR16 filters are Butterworth type filters of 8^{th} and 16^{th} order respectively. These filters offer more flat passband than FIR (especially IIR16), which is constant versus f_c regardless of Filter Cutoff selection. For most Filter Cutoff settings, IIR type filters (especially IIR8) offer a lower filter delay than FIR filters. The disadvantage is that the delay of Butterworth filters is not constant; it varies over input frequency range, making analysis of time correlation of various signals more difficult. Also it causes phase distortions of non-sinusoidal signals.

Each type of filter has seven base cutoff frequencies (Filter Cutoff settings: 1/10, 1/8, 1/6, 1/5, 1/4, 1/3 and 1/2.5), where a different set of filter coefficients is used for digital signal processing (DSP) maths in the final filtering block. These filters operate at twice the specific parameter output sample rate, therefore, the filter sample stream is decimated by a factor of 2 to produce the parameter sample stream. It is possible to output at the maximum sampling rate for these filters.

As for the remaining cutoff frequencies (Filter Cutoff settings: 1/2, 1, 2, 4, 8, 16), the filter uses coefficients as per 1/4 Filter Cutoff setting, but operates at a higher sample rate and uses decimation to produce the final output sample stream. As a result, the target filter cutoff value is effectively achieved. The downside of this approach is that it limits the maximum sampling frequency. Also, the module should not be configured whereby the parameter sample rate and filter cutoff setting would result in the maximum specified f_c for the card being exceeded.

Understanding filter delays (IIR8 and IIR16 filter modes)

The Axon uniquely samples all signals at the start of an acquisition cycle and at equal intervals of time thereafter. Signals sampled at the same sample rate are always sampled at the same time, independently of how they are stored or transmitted. (This has significant advantages for issues such as time correlation.) However, before signals are sampled they are filtered to remove noise components that might alias. The recommended Filter Cutoff setting is 1/4 or lower for IIR8 Filter Mode setting, or 1/2.5 or lower for IIR16 Filter Mode setting, as this results in the maximum filtering of aliasing frequencies. The Axon filters signals using over-sampling signal processing techniques. The following two figures show a delay for an 8th order filter (IIR8 setting) and a 16th order filter (IIR16 setting) normalized to f_c. Charts are plotted up to the Nyquist frequency of the output sample stream where the Filter Cutoff setting is 1/4. Where a higher Filter Cutoff setting is used, a delay chart should be considered only up to the Nyquist frequency of the output sample stream (f_s / 2), as frequencies above the Nyquist frequency are already aliased signals and cannot be easily analyzed.

All filters cause a delay inversely proportional to the filter cutoff frequency (f_c), so to calculate the delay for other f_c values, divide the delay by f_c (expressed in Hz). The frequency axis then needs to be rescaled to the new f_c by multiplying the normalized frequency values by f_c. For example, an 8th order Butterworth filter with an f_c of 1 kHz delays a 1 kHz signal by 1 ms; a filter with an f_c of 10 Hz delays a 10 Hz signal by 0.1 s. The delay for IIR filters (for example Butterworth) varies with the input frequency.

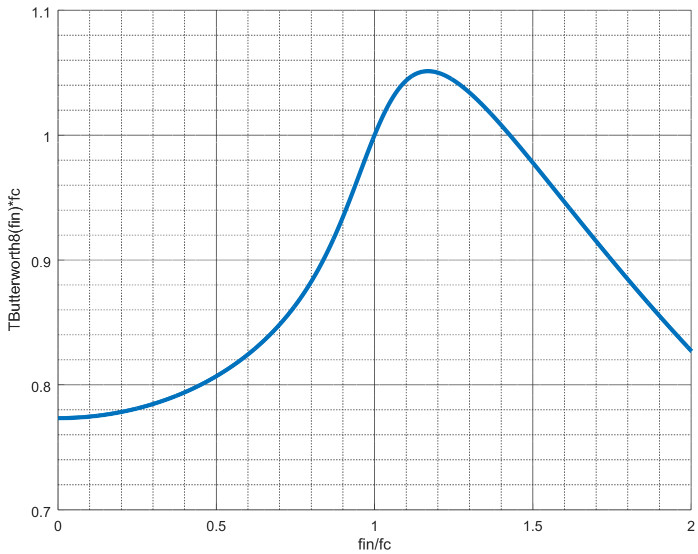

Figure 4: Filter delay for IIR8 Filter Mode setting normalized to f_c

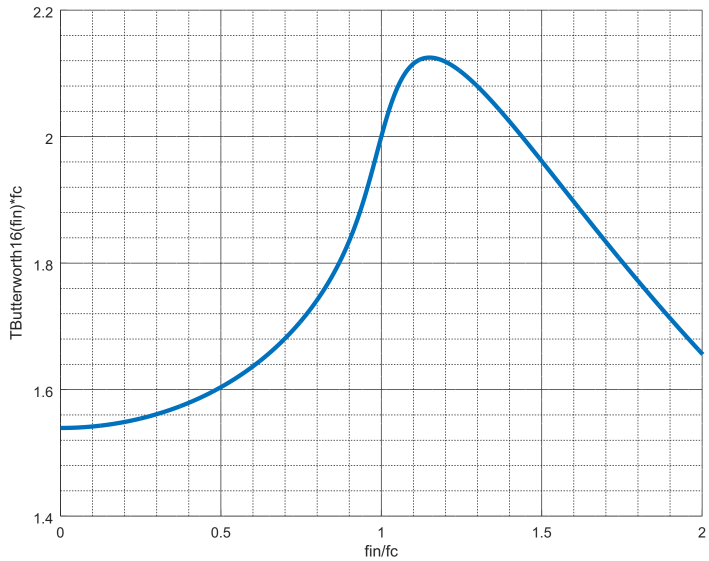

Figure 5: Filter delay for IIR16 Filter Mode setting normalized to f_c

The filter delay for the AXN/TDC/401 is:

$$T_D \approx T_A + \frac{1}{f_C} + T_{Butterworth}\left(f_{in}\right)$$

T_D is the filter delay

T_A (analog filter delay) ≈ 0

Understanding filter delays (FIR filter mode, Filter Cutoff settings of 1/4, 1/2, 1, 2, 4, 8 and 16)

The Axon uniquely samples all signals at the start of an acquisition cycle and at equal intervals of time thereafter. Signals sampled at the same sample rate are always sampled at the same time independently of how they are stored or transmitted. (This has significant advantages for issues such as time correlation.) However, before signals are sampled they are filtered to remove noise components that might alias. The recommended Filter Cutoff setting is 1/4 or lower for FIR Filter Mode setting, as this results in the maximum filtering of aliasing frequencies. The Axon filters signals using over-sampling signal processing techniques. All filters cause a delay inversely proportional to the filter cutoff frequency (f_c).

The filter delay for this mode and these f_c settings is:

$$T_D \approx T_A + \frac{4}{f_c}$$

T_D is the filter delay

T_A (analog filter delay) ≈ 0

Understanding filter delays (FIR filter mode, Filter Cutoff settings of 1/10, 1/8, 1/6, 1/5, 1/3, 1/2.5)

For this FIR mode and its f_c settings, the filter delay formula is different than in the previous section. The delay is such that the Filter Cutoff is 1/4 for FIR mode (the FIR filters delay is not f_c dependent, but rather dependent on the rate and number of filter taps).The following formula effectively defines the delay:

$$T_D \approx T_A + \frac{16}{f_s}$$

T_D is the filter delay

T_A (analog filter delay) ≈ 0

Aliasing

Aliasing is an effect in signal sampling systems, which can cause sampled signals greater than half the sample rate to become indistinguishable from signals in the bandwidth of interest. To prevent the possibility of aliasing, sampling systems offer filtering. With Axon modules, filtering consists of a pre-sampler analog anti-aliasing filter and a post-sampler cascaded digital filter. Axon analog modules support three main types of digital filters: IIR8; IIR16; and FIR. Each can be configured to a various Filter Cutoff frequencies, allowing you to select the cutoff frequency best suited to the application.

One criteria may be aliasing attenuation. Aliasing figures presented in the Specifications tables (starting on page 2) are met or exceeded for Filter Cutoff settings lower or equal to 1/4. For higher Filter Cutoff settings (1/3 and 1/2.5, which still offer Filter Cutoff below the Nyquist frequency), the worst case figures may be lower due to the proximity of the cutoff frequency to the Nyquist frequency and the limited attenuation a specific filter type can achieve for the closest possible aliasing frequencies.

The following table below presents the theoretical worst case aliasing values for the Filter Cutoff settings for the three main filter types.

TABLE 6	Theoretical worst case aliasing values				
PARAMETER	MIN.	TYP.	MAX.	UNITS	CONDITION/DETAILS
IIR8					
aliasing to 0.1 dB bandwidth	–	–	-75	dB	Filter Cutoff setting of 1/3.
aliasing to f_c	–	–	-70	dB	Filter Cutoff setting of 1/3.
aliasing to 0.1 dB bandwidth	–	–	-60	dB	Filter Cutoff setting of 1/2.5.
aliasing to f_c	–	–	-40	dB	Filter Cutoff setting of 1/2.5.
IIR16					
aliasing to 0.1 dB bandwidth	–	–	-75	dB	Filter Cutoff setting of 1/3 and 1/2.5.
aliasing to f_c	–	–	-75	dB	Filter Cutoff setting of 1/3 and 1/2.5.
FIR					
aliasing to 0.1 dB bandwidth	–	–	-72	dB	Filter Cutoff setting of 1/3 and 1/2.5.
aliasing to f_c	–	–	-70	dB	Filter Cutoff setting of 1/3 and 1/2.5.

Use of Filter Cutoff settings of 1/2 and higher is not recommended. While using a Filter Cutoff of 1/2 or higher can help to lower filter delays through the system and/or improve AC gain error within the bandwidth of interest, it may cause significant aliasing due to not meeting the Nyquist criteria.

User compensation

The module offers optional user-compensation per channel. It is linear correction, which can be applied at the digital signal processing path, just after the A/D converter and the channel's correction blocks, but before junction compensation, user range scaling, digital filtering, and output linearization. It allows samples to be corrected by first applying multiplication through user-defined gain compensation values and then adding a user-offset compensation value to produce the output value.

The User Compensation Channel setting determines if compensation is disabled (No compensation), if it is constant correction (Channel independent), or if the selected correction coefficients depends on another parameter (any other channel or one of the module temperature sensors).

Examples where this feature can be used include user calibration/correction of module channel and external sensor/cabling errors compensation. Both uses may also be dependent on one of the other parameters of the module (for example, channel correction could depend on module temperature, or external sensor correction on some other channel).

The User Compensation URL setting links to a file with compensation coefficients. This file could contain either a single set of gain and offset compensation coefficients, or could contain multiple sets with information for what value of reference compensation channel, specific set of gain and offset compensation coefficients is valid. In the latter case, the module compensation block interpolates linearly output value for any value of reference compensation channel between defined compensation channel values, allowing smooth correction change. If the correction channel value is outside of the range defined in User Compensation URL, then correction coefficients of closest defined compensation channel value are used.

Two example files of User Compensation are distributed with DAS Studio 3 software (see DASStudio\3.x\LookupFiles\Examples folder). These files contain a set of three values for each defined compensation point: *ReferenceSourceValue*, *Gain* and *Offset*. ReferenceSourceValue is the point at which a specified pair of Gain and Offset is defined. Gain is a gain correction. Offset is the offset value to be applied, expressed in volts.

For the Channel Independent setting of User Compensation Channel, only one set of values is expected in the compensation file, and ReferenceSourceValue could contain any value there (for example 0) as it is effectively ignored. In a situation where compensation depends on an other channel (for example Module temperature sensor), multiple groups of compensation points are expected, each defined for different ReferenceSourceValue.

DAS Studio 3 software takes the user defined sets of compensation points, interpolates between them, and extrapolates outside the minimum and maximum ReferenceSourceValue (rails corrections to the nearest), and loads such points into the non-volatile settings of module memory in the form of a compensation table. The module itself uses this table to calculate compensation gain and offset values based on the current output value from the selected User Compensation Channel. This calculation is further interpolated based on the nearest points within the non-volatile memory compensation table.

NOTE: Some corrections may cause demand of very different voltage ranges than if compensation was not used. This may lead to compilation errors when the maximum allowed operating range defined for a specific channel is exceeded.

Signal filtering on cold junction channels

As well as an RF filter on the cold junction channels, the AXN/TDC/401 provides a digital filter, which is built into the analog-to-digital converter. This means—unlike other Curtiss-Wright analog modules—the filter characteristics of the AXN/TDC/401 reference junction channels are fixed. The cutoff frequency (-3 dB) point is approximately at 4 Hz and is not dependent on the sampling rate that is used.

The built-in digital filter has 50 Hz and 60 Hz attenuation (>65 dB), and similar attenuation for frequencies above 90 Hz. The following figure shows the magnitude characteristic of the filter.

(Image used with permission of Analog Devices, Inc.)

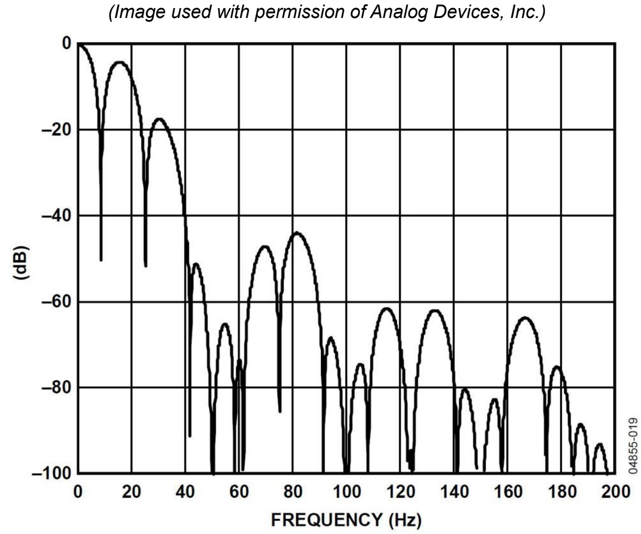

Figure 6: Magnitude characteristic of built-in A/D digital filter

Unused inputs

It is recommended that unused input channels are not left floating, as this may introduce more noise into the system and so degrade card performance, and may increase module power consumption of the order of 30 mW per every channel which is left floating. The easiest way to avoid floating inputs is to set the Pull-down Resistor setting to Enabled on unused channels, and short TEMPERATURE(x)+ input with TEMPERATURE(x)- input on the channel.

Connector pinout of the AXN/TDC/401

PIN	NAME	SEE SPECIFICATIONS TABLE	COMMENT
1	TEMPERATURE(12)+	Thermocouple inputs	
2	TEMPERATURE(12)-	Thermocouple inputs	
3	TEMPERATURE(0)+	Thermocouple inputs	
4	TEMPERATURE(0)-	Thermocouple inputs	
5	TEMPERATURE(1)+	Thermocouple inputs	
6	TEMPERATURE(1)-	Thermocouple inputs	
7	TEMPERATURE(2)+	Thermocouple inputs	
8	TEMPERATURE(2)-	Thermocouple inputs	
9	TEMPERATURE(3)+	Thermocouple inputs	
10	TEMPERATURE(3)-	Thermocouple inputs	
11	TEMPERATURE(4)+	Thermocouple inputs	
12	TEMPERATURE(4)-	Thermocouple inputs	
13	TEMPERATURE(5)+	Thermocouple inputs	
14	TEMPERATURE(5)-	Thermocouple inputs	
15	TEMPERATURE(13)+	Thermocouple inputs	
16	TEMPERATURE(13)-	Thermocouple inputs	
17	DNC		Do not connect
18	EXCITATION(0)+	Cold junction inputs	Excitation current to cold junction channel 0
19	JUNCTION(0)+	Cold junction inputs	Sense line for cold junction channel 0
20	DNC		Do not connect
21	DNC		Do not connect
22	JUNCTION(0)-	Cold junction inputs	Sense line for cold junction channel 0
23	EXCITATION (0)-	Cold junction inputs	Excitation current from cold junction channel 0
24	EXCITATION (1)+	Cold junction inputs	Excitation current to cold junction channel 1
25	JUNCTION(1)+	Cold junction inputs	Sense line for cold junction channel 1
26	DNC		Do not connect
27	DNC		Do not connect
28	JUNCTION(1)-	Cold junction inputs	Sense line for cold junction channel 1
29	EXCITATION (1)-	Cold junction inputs	Excitation current from cold junction channel 1
30	EXCITATION (2)+	Cold junction inputs	Excitation current to cold junction channel 2
31	JUNCTION(2)+	Cold junction inputs	Sense line for cold junction channel 2
32	DNC		Do not connect
33	DNC		Do not connect
34	JUNCTION(2)-	Cold junction inputs	Sense line for cold junction channel 2
35	EXCITATION (2)-	Cold junction inputs	Excitation current from cold junction channel 2
36	TEMPERATURE(14)+	Thermocouple inputs	
37	TEMPERATURE(14)-	Thermocouple inputs	
38	TEMPERATURE(6)+	Thermocouple inputs	
39	TEMPERATURE(6)-	Thermocouple inputs	
40	TEMPERATURE(7)+	Thermocouple inputs	
41	TEMPERATURE(7)-	Thermocouple inputs	
42	TEMPERATURE(8)+	Thermocouple inputs	
43	TEMPERATURE(8)-	Thermocouple inputs	
44	TEMPERATURE(9)+	Thermocouple inputs	
45	TEMPERATURE(9)-	Thermocouple inputs	
46	TEMPERATURE(10)+	Thermocouple inputs	
47	TEMPERATURE(10)-	Thermocouple inputs	
48	TEMPERATURE(11)+	Thermocouple inputs	
49	TEMPERATURE(11)-	Thermocouple inputs	
50	GND	Internal ground	
51	GND	Internal ground	
52	CHASSIS	Chassis	

Ordering information

PART NUMBER	DESCRIPTION
AXN/TDC/401	Thermocouple ADC (cold junction compensation, 3.125 kHz b/w) - 15ch at 12.5 ksps

By default, the standard mating connector (CON/KAD/002/CP) and the standard backshell (ACD/BAC/002/B) are included with each module in the shipment. Their part numbers will be added to the Confirmation of Order unless an alternative option is specified. Optionally, an ACD/CJB/003 can be ordered.

Revision history

REVISION	DIFFERENCES	STATUS
AXN/TDC/401	First release	Recommended for new programs

Supporting software

MODULE	DETAILS
DAS Studio 3	User interface for setup and management of data acquisition, network switches, recorders and ground stations in an integrated environment

Related products

MODULE	DETAILS
GS Works 9	Real-time and post-test data visualization and analysis software
ACD/CJB/003	Cold junction block for KAD/TDC/102 (built in sensors, straight-through backshell) - 15ch
ACD/BAC/002/B	Nickel-plated aluminum straight-through backshell for KAD connectors
CON/KAD/010	Mating connector for KAD/TDC/102 and KAD/TDC/107 (DD, 52-way, 3 built-in temperature sensors)

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Related documentation

DOCUMENT	DETAILS
DOC/MAN/030	DAS Studio 3 User Manual
DOC/DBK/011	AXN Databook
DOC/HBK/008	Environmental Qualification Handbook for Axon Products.
TEC/NOT/010	Thermocouples
TEC/NOT/019	Digital filtering
TEC/NOT/023	Resistance temperature detectors
TEC/NOT/082	Analog modules specifications explained