A-3 Analog Input [T-Series Datasheet]

Please see device-specific subsections below.

A-3-1 T4 Analog Input [T-Series Datasheet]

Please see subsections below.

A-3-1-1 T4 AIN General Specs [T-Series Datasheet]

T4

This T4 section is under construction. Please check back later for correct information. In the meantime look at the U3 analog inputs specs which are almost identical to the T4.

Table A.3-1. T4 Analog Input Information. Specifications at 25 degrees C and Vusb/Vext = 5.0V, except where noted.

Parameter	**Conditions**	**Min**	**Typical**	**Max**	**Units**
General					
USB Cable Length				5	meters
Supply Voltage		4	5	5.25	volts
Supply Current (1)	Hardware V1.2+		50		mA
Operating Temperature		-40		85	°C
Clock Error	-40 to 85 °C			1.5	%
Typ. Command Execution Time (2)	USB high-high	0.6			ms
	USB other	4			ms
VS Outputs					
Typical Voltage (3)	Self-Powered	4.75	5	5.25	volts
	Bus-Powered	4	5	5.25	
Maximum Currrent (3)	Self-Powered		450		mA
	Bus-Powered		50		mA
(1) Typical current drawn by the T4 itself, not including any user connections.					
(2) Total typical time to execute a single Feedback function with no analog inputs. Measured by timing a Windows application that performs 1000 calls to the Feedback function. See Section 3.1 for more timing information.					
(3) These specifications are related to the power provided by the host/hub. Self- and bus-powered describes the host/hub, not the U3. Self-powered would apply to USB hubs with a power supply, all known desktop computer USB hosts, and some notebook computer USB hosts. An example of bus-powered would be a hub with no power supply, or many PDA ports. The current rating is the maximum current that should be sources					

through the U3 and out of the Vs terminals.

Parameter	**Conditions**	**Min**	**Typical**	**Max**	**Units**
Analog Inputs					
Typical input Range (4)	Single-Ended, LV	0		2.44	volts
	Differential, LV	-2.44		2.44	volts
	Special, LV	0		3.6	volts
	Single-Ended, HV	-10.3		10.3	volts
	Special, HV	-10.3		20.1	volts
Max AIN Voltage to GND (5)	Valid Readings, LV	-0.3		3.6	volts
	Valid Readings, HV	-12.8		20.1	volts
Max AIN Voltage to GND (6)	No Damage, FIO	-10		10	volts
	No Damage, EIO	-6		6	volts
	No Damage, HV	-40		40	volts
Input Impedance (7)	LV		40		MΩ
	HV		1.3		MΩ
Source Impedance (7)	Long Settling Off, LV			10	kΩ
	Long Settling On, LV			200	kΩ
	Long Settling Off, HV			1	kΩ
	Long Settling On, HV			1	kΩ
Resolution	All Ranges		12		bits
	Single-Ended, LV, 0-2.44		0.6		mV
	Differential, LV, ±2.44		1.2		mV
	Special, LV, 0-3.6		1.2		mV
	Single-Ended, HV, ±10		5.0		mV
	Special, HV, -10 to +20		10.0		mV
Integral Linearity Error			±0.05		% FS
Differential Linearity Error			±1		counts
Absolute Accuracy (8)	Single-Ended %		±0.13		% FS
	Single-Ended LV volts		±3.2		mV
	Single-Ended HV volts		±26.8		mV
	Differential %		±0.25		% FS
	Differential LV volts		±6.4		mV
	Differential HV volts		N/A		
	Special 0-3.6 %		±0.25		% FS
	Special LV volts		±6.4		mV
	Special HV volts		±53.6		mV
Temperature Drift			15		ppm/°C
Noise (Peak-To-Peak) (9)	Quick Sample Off		±1		counts
	Quick Sample On		±2		counts
Effective Resolution (RMS) (10)	Quick Sample Off		>12		bits
Noise-Free Resolution (9)	Quick Sample Off		11		bits
Command/Response Speed	See Section 3.1				
Stream Performance	See Section 3.2				

* LV specs refer to low voltage analog inputs which are available on the U3-LV and U3-HV. HV specs refer to high voltage analog inputs which are available on the U3-HV only.

(4) Note that these are typical input ranges. The actual minimum on the low voltage inputs might not go all the way to 0.0 as discussed in Section 2.6.3.9. These are with DAC1 disabled on hardware version < 1.30.

(5) This is the maximum voltage on any AIN pin compared to ground for valid measurements. Note that a differential channel has a minimum voltage of -2.44 volts, meaning that the positive channel can be 2.44 volts less than the negative channel, but no low-voltage AIN pin can go more than 0.3 volts below ground.

(6) Maximum voltage, compared to ground, to avoid damage to the device. Protection level is the same whether the device is powered or not.

(7) The low-voltage analog inputs essentially connect directly to a SAR ADC on the U3, presenting a capacitive load to the signal source. The high-voltage inputs connect first to a resistive level-shifter/divider. The key specification in both cases is the maximum source impedance. As long as the source impedance is not over this value, there will be

no substantial errors due to impedance problems.

(8) Absolute error includes INL, DNL, and all other sources of internal error at 25 C and VS=5.0V. To equate the percentage to voltage, multiply the full voltage span by the percentage. For a single-ended low voltage input using the normal range the span is about 2.4 volts, so 2.4 * 0.0013 gives ±0.003 volts. For a single-ended high voltage input using the normal range the span is about 20 volts, so 20 * 0.0013 gives ±0.026 volts. Differential readings are not calibrated on high voltage channels.

(9) Measurements taken with AIN connected to a 2.048 reference (REF191 from Analog Devices) or GND. All "counts" data are aligned as 12-bit values. Noise-free data is determined by taking 128 readings and subtracting the minimum value from the maximum value.

(10) Effective (RMS) data is determined from the standard deviation of 128 readings. In other words, this data represents _most_ readings, whereas noise-free data represents all readings.

Parameter	Conditions	Min	Typical	Max	Units
Analog Outputs (DAC)					
Nominal Output Range (11)	No Load	0.04		4.95	volts
	@ ±2.5 mA	0.225		4.775	volts
Resolution			10		bits
Absolute Accuracy	5% to 95% FS		±5		% FS
Integral Linearity Error			±1		counts
Differential Linearity Error			±1		counts
Max Output Current (12)	@ 2.0V		30		mA
Error Due To Loading (12)	@ 100 µA		0.1		%
	@ 1 mA		1		%
Source Impedance (12)			50		Ω
Short Circuit Current (12,13)	5V to GND		50		mA
Cutoff Frequency (14)	-3 dB		16		Hz
Time Constant (14)			10		ms
Digital I/O, Timers, Counters					
Low Level Input Voltage		-0.3		0.8	volts
Hight Level Input Voltage		2		5.8	volts
Maximum Input Voltage (15)	FIO	-10		10	volts
	EIO/CIO	-6		6	volts
Output Low Voltage (16)	No Load		0		volts
--- FIO	Sinking 1 mA		0.55		volts
--- EIO/CIO	Sinking 1 mA		0.18		volts
--- EIO/CIO	Sinking 5 mA		0.9		volts
Output High Voltage (16)	No Load		3.3		volts
--- FIO	Sourcing 1 mA		2.75		volts
--- EIO/CIO	Sourcing 1 mA		3.12		volts
--- EIO/CIO	Sourcing 5 mA		2.4		volts
Short Circuit Current (16)	FIO		6		mA
	EIO/CIO		18		mA
Input Impedance	Pull-up to 3.3V		100		kΩ
Output Impedance (16)	FIO		550		Ω
	EIO/CIO		180		Ω
Counter Input Frequency (17)	Hardware V1.21+			8	MHz
Input Timer Total Edge Rate (18)	No Stream, V1.21+			30000	edges/s
	While Streaming			7000	edges/s

(11) Maximum and minimum analog output voltage is limited by the supply voltages (Vs and GND). The specifications assume Vs is 5.0 volts. Also, the ability of the DAC output buffer to driver voltages close to the power rails, decreases with increasing output current, but in most applications the output is not sinking/sourcing much current as the output voltage approaches GND.

(12) If the output is set to 3.5 volts and sourcing 30 mA, there will be about 2.0 volts at the DAC pin due to the 50 ohms of series impedance. Each DAC output is driven by a channel on an AD8544 op-amp, powered by VS & GND, and then goes through protection circuitry that includes 50 ohms of series impedance. The max output current is determined by 3 main factors: short circuit current, ability of AD8544 to sink/source near

power rails (Figure 22 of AD8544 datasheet), and the 50 ohms of series impedance.
(13) Continuous short circuit will not cause damage.
(14) The DAC outputs are creating by filtering PWM signals, and the 2nd order 16 Hz output filter works great for the default PWM frequency of 732 Hz, but with lower frequency timer clocks the DAC outputs will be noisier. See Section 2.7 for more details. Time constant is the time it take for the output to settle 63% of the way towards a new value.
(15) Maximum voltage to avoid damage to the device. Protection works whether the device is powered or not, but continuous voltages over 5.8 volts or less than -0.3 volts are not recommended when the U3 is unpowered, as the voltage will attempt to supply operating power to the U3 possible causing poor start-up behavior.
(16) These specifications provide the answer to the question: "How much current can the digital I/O sink or source?". For instance, if EIO0 is configured as output-high and shorted to ground, the current sourced by EIO0 into ground will be about 18 mA (3.3/180). If connected to a load that draws 5 mA, EIO0 can provide that current but the voltage will droop to about 2.4 volts instead of the nominal 3.3 volts. If connected to a 180 ohm load to ground, the resulting voltage and current will be about 1.65 volts @ 9 mA.
(17) Hardware counters. 0 to 3.3 volt square wave. Limit 2 MHz with older hardware versions.
(18) To avoid missing edges, keep the total number of applicable edges on all applicable timers below this limit. See Section 2.9 for more information. Limit 10000 with older hardware versions.

See also: Appendix A-3-1 Noise and Resolution

A-3-1-2 T4 Noise and Resolution [T-Series Datasheet]

T-series Appendix Analog Input Noise and Resolution (Referencable)

ADC Noise and Resolution

T-series devices use an internal analog-to-digital converter (ADC) to convert analog voltage into digital representation. The ADC reports an analog voltage in terms of ADC counts, where a single ADC count is the smallest change in voltage that will affect the reported ADC value. A single ADC count is also known as the converter's least significant bit (LSB) voltage. The ADC's resolution defines the number of discrete voltages represented over a given input range. For example, a 16-bit ADC with a ±10 input range can report 65536 discrete voltages (2^{16}) and has an LSB voltage of 0.305 mV ($20\ V \div 2^{16}$).

The stated resolution for an ADC is a theoretical, best-case value assuming no channel noise. In reality, every ADC works in conjunction with external circuitry (amplifiers, filters, etc.) which all possess some level of inherent noise. The noise of supporting hardware, in addition to noise of the ADC itself, all contribute to the channel resolution. In general, the resolution for an ADC and supporting hardware will be less than what is stated for the ADC. The combined resolution for an in-system ADC is termed effective resolution. Simply put, the effective resolution is the equivalent resolution where analog voltages less than the LSB voltage are no longer differentiable from the inherent hardware noise.

The effective resolution is closely related to the error free code resolution (EFCR) or*flicker-free* code resolution. The EFCR represents the resolution on a channel immune to "bounce" or "flicker" from the inherent system noise. The EFCR is not reported in this appendix. However, it may be closely approximated by the following equation:

EFCR = effective resolution - 2.7 bits [1]

The T4 and the T7 offer user-selectable effective resolution through the resolution index parameter on any one AIN channel. Internally, the ADC hardware uses modified sampling methods to reduce noise. Valid resolution index values are:

- 0-5 for the T4
- 0-8 for the T7
- 0-12 for the T7-Pro [2][3]

Increasing the resolution index value will improve the channel resolution, but doing so will usually extend channel sampling times. See section 14.0 AIN for more information on the resolution index parameter and its use.

T4 Appendix Analog Input Noise and Resolution (Referencable)

T4

> The T4 is a 12-bit class device. See Appendix A-1 for typical effective resolution.

A-3-1-3 T4 Signal Range [T-Series Datasheet]

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T4 AIN Signal Range

> Analog inputs on the T4 are single-ended only. That means the voltage of a given input terminal is acquired versus GND, and thus the signal range is simply the same as the analog input ranges of ±10V or 0-2.5V discussed in various places. See Appendix A-3 for further analog input specs.

A-3-2 T7 Analog Input [T-Series Datasheet]

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Please see the subsections below.

A-3-2-1 T7 AIN General Specs [T-Series Datasheet]

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T7

Table A.3-2. T7 Analog Input Information. All specs at room temperature unless otherwise noted.

	Conditions	Min	Typical	Max	Units
Typical Input Range [1]	Gain=1	-10.5		10.1	Volts
Max AIN Voltage to GND [2]	Valid Readings	-11.5		11.5	Volts
Max AIN Voltage to GND [3]	No Damage	-20		20	Volts
Input Bias Current [4]			20		nA
Input Impedance [4]			1		GΩ
Max Source Impedance [4]			1		kΩ
Integral Linearity Error	Range=10, 1, 0.1			±0.01	%FS
	Range=0.01			±0.1	%FS
Absolute Accuracy	Range=10, 1, 0.1			±0.01	%FS
	Range=10			±2000	µV
	Range=1			±200	µV
	Range=0.1			±20	µV
	Range=0.01			±0.1	%FS
	Range=0.01			±20	µV
Temperature Coefficient			15		ppm/°C
Channel Crosstalk [5]	< 1kHz		-100		dB
	1kHz - 50kHz		20		dB/dec

High-Speed ADC -3dB Frequency [6]	Gain=1, 10		445		kHz
	Gain=100		337		kHz
	Gain=1000		63		kHz
High-Res ADC -3dB Frequency [7]	See Note #7				
Noise (Peak-To-Peak)	See A-3-2			<1	µV
Effective Resolution (RMS)	See A-3-2			22	bits
Noise-Free Resolution	See A-3-2			20	bits
[1] Differential or single-ended					
[2] This is the maximum voltage on any AIN pin compared to ground for valid measurements on that channel. For single-ended readings on the channel itself, inputs are limited by the "Typical Input Range" above, and for differential readings consult Appendix A-3-2 Signal Range. Further, if a channel has over 13.0 volts compared to ground, readings on other channels could be affected. Because all even channels are on one front-end mux and all odd channels on a second front-end mux, an overvoltage (>13V) on a single channel will generally affect only even or only odd channels.					
[3] Maximum voltage, compared to ground, to avoid damage to the device. Protection level is the same whether the device is powered or not.					
[4] The key specification here is the maximum source impedance. As long as your source impedance is not over this value, there will be no substantial errors due to impedance problems. For source impedance greater than this value, more settling time might be needed.					
[5] Typical crosstalk on a grounded AIN pin, with 20Vpp sine wave on adjacent AIN pin. An adjacent AIN pin refers to multiplexer channel location not channel number, e.g. AIN0-AIN2 or AIN1-AIN3 pairs.					
[6] This is the bandwidth of the analog hardware. Any frequencies less than this will go through the analog system to the ADC and be part of the digitized waveform. For DC measurements this is of little concern as ResolutionIndex and averaging can be used to get rid of extra noise. For AC measurements, frequency components below the nyquist point can be removed after digitizing, but frequency components above the nyquist point must be removed before digitizing as they will alias. If unwanted signals with frequencies between the nyquist point and analog cutoff frequency are expected, and they are expected to have sufficient magnitude to be above the acceptable noise level, then an external hardware filter must be used (often called an anti-alias or anti-aliasing filter).					
[7] The fixed -3dB frequencies from note 6 apply to the high-speed ADC (ResolutionIndex = 1-8), but the high-resolution ADC on the T7-Pro (ResolutionIndex = 9-12) has filtering at much lower frequencies. The frequency response at ResolutionIndex=12 is shown in Figure 22 of the AD7190 datasheet. For the response at ResIndex 9/10/11 multiply those x-axis values by 47.9/12.0/2.4. Figure 22 only shows up to 150 Hz, but know that all higher frequencies are also filtered out, except for a narrow passband at 307 kHz. The width of this passband is about 200 Hz at ResIndex=12 increasing to about 10000 Hz at ResIndex=9.					

See also: Appendix A-3-2 Noise and Resolution

A-3-2-2 T7 Noise and Resolution [T-Series Datasheet]

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T-series Appendix Analog Input Noise and Resolution (Referencable)

ADC Noise and Resolution

T-series devices use an internal analog-to-digital converter (ADC) to convert analog voltage into digital representation. The ADC reports an analog voltage in terms of ADC counts, where a single ADC count is the smallest change in voltage that will affect the reported ADC value. A single ADC count is also known as the converter's least significant bit (LSB) voltage. The ADC's resolution defines the number of discrete voltages represented over a given input range. For example, a 16-bit ADC with a ±10 input range can report 65536 discrete voltages (2^{16}) and has an LSB voltage of 0.305 mV ($20\ \text{V} \div 2^{16}$).

The stated resolution for an ADC is a theoretical, best-case value assuming no channel noise. In reality, every ADC works in conjunction with external circuitry (amplifiers, filters, etc.) which all possess some level of inherent noise. The noise of supporting hardware, in addition to noise of the ADC itself, all contribute to the channel resolution. In general, the resolution for an ADC and supporting hardware will be less than what is stated for the ADC. The combined resolution for an in-system ADC is termed effective resolution. Simply put, the effective resolution is the equivalent resolution where analog voltages less than the LSB voltage are no longer differentiable from the inherent hardware noise.

The effective resolution is closely related to the error free code resolution (EFCR) or*flicker-free* code resolution. The EFCR represents the resolution on a channel immune to "bounce" or "flicker" from the inherent system noise. The EFCR is not reported in this appendix. However, it may be closely approximated by the following equation:

EFCR = effective resolution - 2.7 bits [1]

The T4 and the T7 offer user-selectable effective resolution through the resolution index parameter on any one AIN channel. Internally, the ADC hardware uses modified sampling methods to reduce noise. Valid resolution index values are:

- 0-5 for the T4
- 0-8 for the T7
- 0-12 for the T7-Pro [2][3]

Increasing the resolution index value will improve the channel resolution, but doing so will usually extend channel sampling times. See section 14.0 AIN for more information on the resolution index parameter and its use.

T7 Appendix Analog Input Noise and Resolution (Referencable)

T7

The T7 has a 16-bit ADC. The T7-Pro has the same 16-bit ADC plus a lower speed 24-bit sigma-delta ADC.

Noise and Resolution Data

The data shown below summarizes typical effective resolutions and expected channel sampling times over all resolution index values. Data for the T7 and T7-Pro data are combined and presented together for convenience, where resolution index values 9-12 only apply to the T7-Pro.

The AIN sampling time is the typical amount of time required for the ADC hardware to make a single analog to digital conversion on any channel and is reported in milliseconds per sample. The AIN sampling time does not include command/response and overhead time associated with the host computer/application.

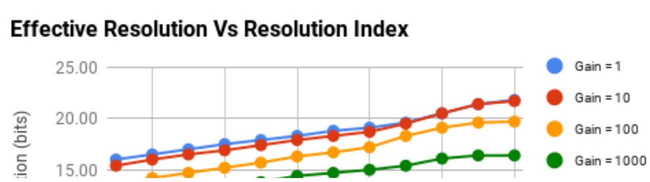
Noise and Resolution Test procedure

Noise and resolution data was generated by collecting 512 successive voltage readings, using a short jumper between the test channel and ground. The resulting data set represents typical noise measured on any one analog input channel in ADC counts. The effective resolution is calculated by subtracting the RMS channel noise (represented in bits) from 16-bits.

$$\text{Effective Resolution} = 16\ \text{bits} - \log_2(\text{RMS Noise [in ADC counts]})$$

Table A.3.1.1. T7 resolution data. Effective resolution and sampling times for various gains and resolution index settings. Resolution index settings 9-12 apply to the T7-Pro only.

Resolution Index	Effective Resolution	Effective Resolution	AIN Sample Time
	[bits]	[µV]	[ms/sample]
Gain/Range: 1/±10V			



1	16.0	316	0.04
2	16.5	223	0.04
3	17.0	158	0.06
4	17.5	112	0.09
5	17.9	85	0.16
6	18.3	64	0.29
7	18.8	45	0.56
8	19.1	37	1.09
9	19.6	26	3.50
10	20.5	14	13.4
11	21.4	7.5	66.2
12	21.8	5.7	159
Gain/Range: 10/±1V			
1	15.4	48	0.23
2	16.0	32	0.23
3	16.5	22	0.55
4	16.9	17	0.58
5	17.4	12	1.15
6	17.9	8.5	2.28
7	18.3	6.4	2.55
8	18.7	4.9	3.08
9	19.5	2.8	3.50
10	20.5	1.4	13.4
11	21.4	0.7	66.2
12	21.7	0.6	159
Gain/Range: 100/±0.1V			
1	13.3	21	1.03
2	14.2	11	2.03
3	14.7	7.8	5.05
4	15.2	5.5	5.08
5	15.7	3.9	5.15
6	16.3	2.6	10.28
7	16.7	1.9	10.55
8	17.2	1.4	11.08
9	18.3	0.6	3.50
10	19.1	0.4	13.4
11	19.6	0.3	66.2
12	19.7	0.2	159
Gain/Range: 1000/±0.01V			
1	10.9	11	5.03
2	12.3	4.1	10.0
3	12.7	3.1	10.1
4	13.3	2.1	10.1
5	13.8	1.5	10.2
6	14.4	1.0	10.3
7	14.7	0.8	10.6
8	15.0	0.6	11.1
9	15.4	0.5	3.50
10	16.1	0.3	13.4
11	16.4	0.2	66.2
12	16.4	0.2	159

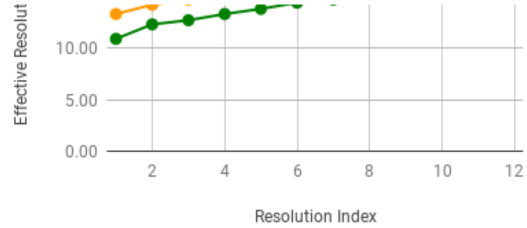


Figure A.3.1.2. T7 analog input effective resolution over various gains and resolution index settings.

Figure A.3.1.3. T7 analog input LSB voltage over various gains and resolution index settings.

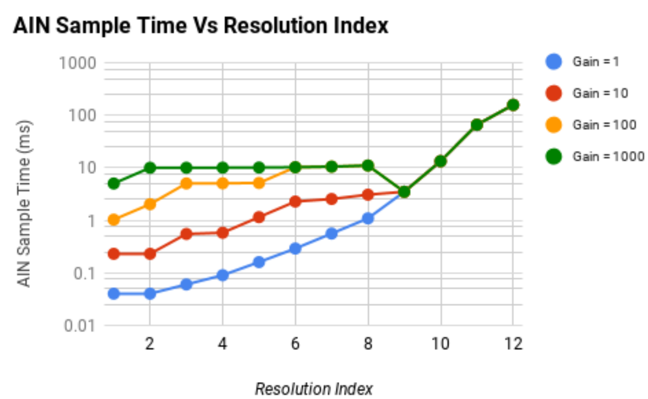


Figure A.3.1.4. T7 AIN sample times for analog inputs over various gains resolution index settings.

Notes:

[1] The equation used to approximate the EFCR is determined using +/-3.3 standard deviations from the RMS noise measured on an AIN channel.

[2] The default value for RESOLUTION_INDEX is 0, which equates to 8 for T7 command-response reads, 9 for T7-Pro command-response reads, and 1 for T7 & T7-Pro stream reads.

[3] The T7-Pro is equipped with a 24-bit delta-sigma ADC, in addition to the standard 16-bit ADC. Analog conversions occur on the 16-bit ADC when resolution index values 0-8 are used. Analog conversions occur on the 24-bit ADC when resolution index values 9-12 are used (command response mode only).

[4] The hi-resolution 24-bit ADC is not supported in stream mode.

A-3-2-3 T7 Signal Range [T-Series Datasheet]

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T7 AIN Signal Range

The instrumentation amplifier in the T7 (see Figure 4.2-2) provides 4 different gains:

- x1 (RANGE is ±10 volts)
- x10 (RANGE is ±1 volts)
- x100 (RANGE is ±0.1 volts)
- x1000 (RANGE is ±0.01 volts)

The input ranges are straightforward for single-ended measurements, but can be a little tricky for differential measurements if neither channel (positive or negative) is at 0 volts.

The figures below show the approximate signal range of the T7 analog inputs at gains of x1 and x1000.

Input Common-Mode Voltage, known as V_{cm}, is:

$$V_{cm} = (V_{pos} + V_{neg})/2$$

The voltage of any input compared to GND should be within the VM+ and VM- rails by at least 1.5 volts, so if VM+ and VM- is the typical ±13 volts, the signals should be within ±11.5 volts compared to GND. See Table A5-8 for more information on VM+ and VM-.

Example #1 - invalid because V_{cm}=10.0 with V_{out}=10.0 is invalid:

Suppose a differential signal is measured, where:

- V_{pos} is 10.05 volts compared to GND
- V_{neg} is 9.95 volts compared to GND
- G=100 (RANGE=±0.1)

That means:

- V_{cm}=10.0 volts,
- V_{diff}=0.1 volts,
- and the expected V_{out}=10.0 volts.

Figures for G=10 and G=100 are not shown, but V_{cm}=10.0 volts and V_{out}=10.0 volts is not valid at G=1 or G=1000, so it is not valid for gains in between.

Example #2 - invalid because V_{pos} compared to GND is too high:

Suppose a differential signal is measured, where:

- V_{pos} is 12.0 volts compared to GND
- V_{neg} is 8.0 volts compared to GND
- G=1 (RANGE=±10)

That means:

- V_{cm}=10.0 volts,
- V_{diff}=4.0 volts,
- and the expected V_{out}=4.0 volts.

This looks almost okay in the G=1 figure below, but the voltage of V_{pos} compared to GND is too high so this is not valid.

Example #3 - valid:

Suppose a single-ended signal is measured, where:

- V_{pos} is 10.0 volts compared to GND
- G=1 (RANGE=±10)

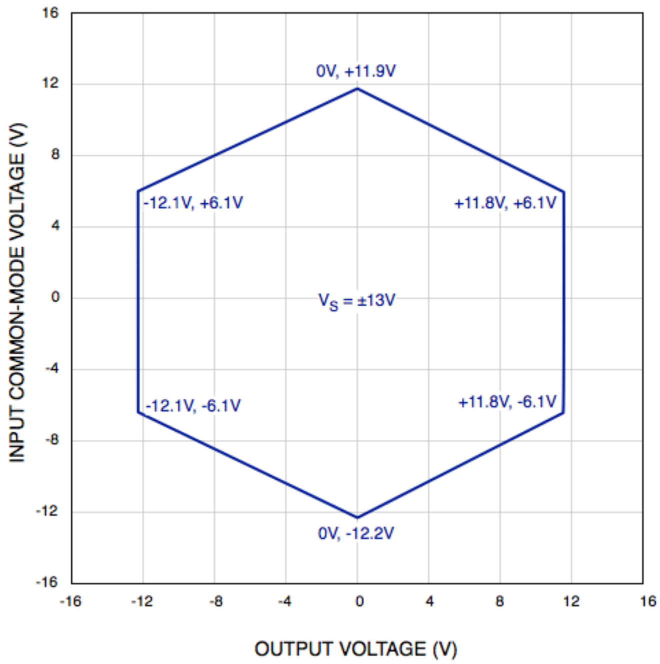
That means:

That means:

- V_{cm}=5.0 volts,
- V_{diff}=10.0 volts,
- and the expected V_{out}=10.0 volts.

This is fine according to the figure below.

Input Common-Mode Voltage Range vs. Output Voltage, G = 1



Input Common-Mode Voltage Range vs. Output Voltage, G = 1000