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Appendix A - Specifications [T-Series Datasheet]

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Appendix A - Specifications Overview

Specifications for describing the T-Series devices can be broken down into several primary sections with a few sub-sections. Navigate the following sections to see specifications.

A-1 Data Rates [T-Series Datasheet]

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Communication Modes

Communication between the host computer and a T-series device occurs using one of two modes:

1. Command-response

   Command-response mode is appropriate for most applications. In command-response mode, the host sends a command data packet, to which the T-series device sends a response data packet.

2. Stream

   Stream mode is when the device collects periodic sampling events automatically. Collected data is stored in the device's memory until it retrieved by the host application. The LJM library stream functions simplify data collection from T-series devices. Not all functionality is supported in stream mode. Please refer to the Stream Mode section of the user's manual for more details.

For more information about command-response and stream, see 3.0 Communication.

Note: These specs are generated using a LabVIEW program that reads data from a device in a simple while(1) loop. Additionally, we used a PC running Windows with a fairly average Intel CPU. We have found the performance of LabVIEW to be very similar to C, C++, and other compiled languages and have therefore chosen LabVIEW to collect these data rates. If an application requires precise timing of CR packets we suggest doing additional research and replicating these results for the system being used.

Figure A1.1.1 depicts the two operating modes.

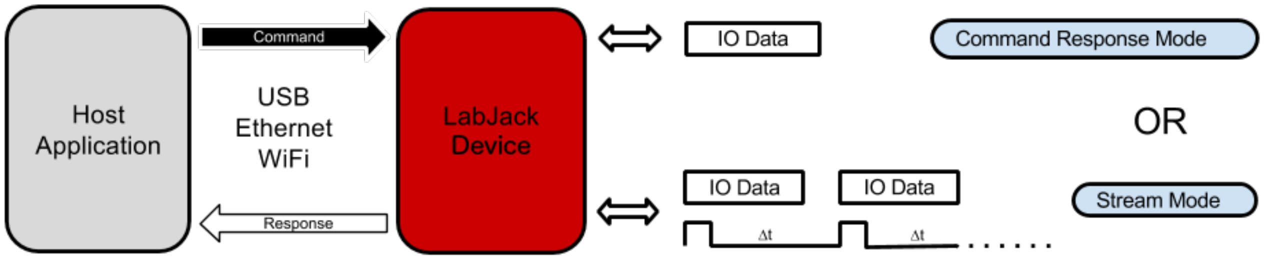

Figure A1.1. Communication modes

The use of a particular mode will depend on functionality and the hardware response time required by the end application.

Command-Response Data Rates

All communication performed with T-series devices is accomplished using the Modbus TCP protocol, thus allowing direct communication with the device via low-level TCP commands. As an alternative, the LJM library may be used as a higher level communications layer for added convenience and minimal additional overhead. Tables A.1.1 and A.1.2 list expected communication overhead times associated with Modbus TCP and LJM Library communication options. These times are similar for all T-series devices, but the following were measured on a T7 (LJM: 1.0706, Firmware: 1.046).

Table A.1.1. Typical communication overhead using direct Modbus TCP.

	USB High-High	USB Other	Ethernet	WiFi
	[ms]	[ms]	[ms]	[ms]
No I/O - Overhead	0.6	2.1	1.0	6.5
Read All DI	0.7	2.2	1.1	6.6
Write All DO	0.7	2.2	1.1	6.6
Write Both DACs	0.7	2.2	1.1	6.6

Table A.1.2. Typical communication overhead using LJM library.

	USB High-High	USB Other	Ethernet	WiFi
	[ms]	[ms]	[ms]	[ms]
No I/O - Overhead	0.6	2.2	1.1	6.7
Read All DI	0.7	2.3	1.2	6.8
Write All DO	0.7	2.3	1.2	6.8
Write Both DACs	0.7	2.3	1.2	6.8

The times shown in table A.1.2 were measured using a LabVIEW program running on Windows where all read and write operations are conducted with a single LJM_eNames() call. The LJM_eNames() functions is used to minimize the number of Modbus packets sent from the host (one packet per command/response set). The test program executes one of the listed tasks within a loop for a specified number of iterations, over a 1-10 second period. The overall execution time is divided by the total number of iterations, providing the average time per iteration for each task. The execution time includes LabVIEW overhead, LJM library overhead, Windows overhead, communication time (USB/Ethernet/WiFi), and device processing time.

A "USB high-high" configuration means the T4/T7 is connected to a high-speed USB2 hub which is then connected to a high-speed USB2 host. Even though the Tx is not a high-speed USB device, such a configuration does often provide improved performance. Typical examples of "USB other" would be a Tx connected to an old full-speed hub (hard to find) or more likely the Tx is connected directly to the USB host (your PC) even if the host supports high-speed.

Preemptive Operating Systems and Thread Priority:

It is important to understand that Linux, Mac OS X, and Windows are generally "best-effort" operating systems and not "real-time", meaning that the listed CR speeds can vary based on each individual computer, the hardware inside of it, its currently enabled peripherals, current network traffic, strength of signal, design of the application software, other running software, and many more variables [1].

USB and Ethernet:

These times are quite predictable. Software issues mentioned above are important—but, in terms of hardware, the times will be consistent. The device communication does not consume a major portion of total USB or Ethernet bandwidth. Therefore, the overhead times listed are typically maintained even with substantial activity on the bus.

WiFi - T7-Pro Only:

> WiFi latency tends to vary more than USB or Ethernet latency. With a solid connection, most WiFi packets have an overhead of 3 to 8 ms, but many will take longer. For example, a test was done in a typical office environment of 1000 iterations that produced an average time of 7.0 ms. The results were:
>
> - 92% of the packets took 3-8 ms,
> - 99% took < 30 ms,
> - and 3 packets took 300 ms.
>
> All WiFi tests were done with an RSSI between -40 (very strong) and -70 (good). An RSSI less than -75 generally reflects a weak connection, causing a greater number of packets retries. An RSSI greater than -35 reflects a very strong connection, typically within a few feet of the access point. This also results in a greater numbers of retries due to saturation of the RF signal.

ADC Conversions:

Analog to digital conversions (ADC) will increase the command-response time depending on the number of channels, the input gain (T7), and the resolution index being used. The following tables list conversion times for various different settings when reading a single analog input channel. The total command-response time (CRT) when reading analog inputs is equal to the overhead time from tables A.1.1 and A.1.2 added to the conversion times for the requested channels:

```
CRT (milliseconds) = overhead + (#AINs * AIN Sample Time)
```

Table A.1.3. Typical C-R milliseconds per sample, T4.

Resolution Index	Effective Resolution [bits]	Effective Resolution [mV]	AIN Sample Time [ms/sample]
High-Voltage Channels (AIN0-AIN3)			
1	11.0	10.4	0.07
2	11.4	7.7	0.11
3	12.3	4.2	0.16
4	12.9	2.7	0.29
5*	13.2	2.2	0.51
Low-Voltage Channels (Applicable FIO & EIO)			
1	10.8	1.2	0.07
2	11.6	0.69	0.11
3	12.0	0.52	0.16
4	12.2	0.43	0.29
5*	12.8	0.29	0.51

* = Default command-response ResolutionIndex for the T4.

Table A.1.4. Typical C-R milliseconds per sample, T7.

Resolution Index	Effective Resolution [bits]	Effective Resolution [µV]	AIN Sample Time [ms/sample]
Gain/Range: 1/±10V			
1	16.0	316	0.04
2	16.5	223	0.04
3	17.0	158	0.1
4	17.5	112	0.1
5	17.9	84.6	0.2
6	18.3	64.1	0.3
7	18.8	45.3	0.6
8*	19.1	36.8	1.1
9**	19.6	26.0	3.5
10	20.5	14.0	13.4
11	21.3	8.02	66.2
12	21.4	7.48	159
Gain/Range:10/±1V			
1	15.4	47.9	0.2
2	16.0	31.6	0.2
3	16.5	22.3	0.6
4	16.9	16.9	0.6
5	17.4	12.0	1.2
6	17.9	8.46	2.3
7	18.3	6.41	2.6
8*	18.7	4.86	3.1
9**	19.5	2.79	3.5
10	20.5	1.40	13.4
11	21.4	0.748	66.2
12	21.5	0.698	159
Gain/Range: 100/±0.1V			

1	13.3	20.5	1.0
2	14.2	11.0	2.0
3	14.7	7.78	5.1
4	15.2	5.50	5.1
5	15.7	3.89	5.2
6	16.3	2.57	10.3
7	16.7	1.94	10.6
8*	17.2	1.37	11.1
9**	18.3	0.641	3.5
10	19.1	0.368	13.4
11	19.6	0.260	66.2
12	19.7	0.243	159
Gain/Range: 1000/±0.01V			
1	10.9	10.8	5.0
2	12.3	4.10	10.0
3	12.7	3.11	10.1
4	13.3	2.05	10.1
5	13.8	1.45	10.2
6	14.4	0.96	10.3
7	14.7	0.778	10.6
8*	15.0	0.632	11.1
9**	15.4	0.479	3.5
10	16.1	0.295	13.4
11	16.4	0.239	66.2
12	16.4	0.239	159

* = Default command-response ResolutionIndex for the T7.
** = Default command-response ResolutionIndex for the T7-Pro.

Streaming Data Rates

The fastest data rates on T-series devices occur when operating in stream mode. Much of the command-response overhead is eliminated in stream mode because the device is responsible for initiating IO operations. The device collects scans in its stream buffer, then the host application retrieves multiple scans at once. The end result is a continuous data stream, sampled at regular intervals, collected with a minimum number of communication packets [2.].

There is an important distinction between *scans* and *samples*. Definitions are as follows:

- Address: Also called a *channel*. An address usually returns the value of 1 input connection.
- Sample: A reading from one address.
- Scan: One reading from every address in the scan list.
- Scan list: The list of one or more addresses in a scan.

The scan rate is the rate at which scans are collected. It is a fraction of the sample rate, where the fraction is the inverse of the number of channels being read in a single scan. The scan rate is defined as:

```
ScanRate = SampleRate / NumAddresses
```

The sample rate and scan rate are equal when the `NumAddresses` is 1.

T4 Stream Rates

he T4 has a **typical maximum sample rate** of 50 ksamples/second. This maximum is reflected in the first row of data in the following table (highlighted). The scan rates reported are the maximum sample rates divided by the number of channels in the scan list (within ~10%).

The scan rates in the following tables are continuous over USB or Ethernet.

The scan rate is defined as (see "Streaming Data Rates" above):

```
ScanRate = SampleRate / NumAddresses
```

Table A.1.5. T4 Stream: Scan rates for different values of resolution index. Applies to USB and Ethernet. Applies to all streamable addresses including low-voltage and high-voltage analog inputs.

	Maximum Scan Rate				**Maximum Sample Rate**
	1 Channel	**2 Channels**	**4 Channels**	**8 Channels**	**>1 Channel**
	[Hz]	[Hz]	[Hz]	[Hz]	[Hz]
Resolution Index = 1*	50k	25k	12.5k	6.25k	50k
Resolution Index = 2	15k	7.5k	3.75k	1.875k	15k
Resolution Index = 3	8k	4k	2k	1k	8k
Resolution Index = 4	4k	2k	1k	500	4k
Resolution Index = 5	2k	1k	500	250	2k

* Default stream ResolutionIndex for the T4.

Table A.1.6. T4 Stream: Typical noise and interchannel delay values depending on resolution index.

Resolution Index	**Peak-to-Peak Noise**	**Interchannel Delay**
	[12-bit counts]	[µs]
1*	±4	40/13**
2	±3	47
3	±2.5	121
4	±2	230
5	±1.5	446

* Default stream ResolutionIndex for the T4.
** 40 µs for sample rate <= 20k. 13 µs for sample rate > 20k.

T7 Stream Rates

- **Ethernet** can usually maintain just under 120 ksamples/second.
- **USB** generally maxes out right around 100 ksamples/second.
- When using **WiFi**, the device can acquire data at the fastest rates, but transfer of data to the host is limited to about 1 ksamples/second, so the fastest stream rates cannot be maintained continuously. In this case, stream-burst can be used rather than continuous stream, where each stream is limited to a specified number of scans that fits in the device's stream buffer. For high-speed wireless streaming, use the Ethernet connection with an external Ethernet-WiFi bridge.

The T7 has a **typical maximum sample rate** of 100 ksamples/second. This maximum sample rate is achievable when a stream is configured with RANGE = ±10V and RESOLUTION_INDEX = 0 or 1 [3.]. This maximum is reflected in the first row of data in table A.1.4

(highlighted). The scan rates reported in table A.1.4 are the maximum sample rates divided by the number of channels in the scan list (within ~10%).

The scan rates in the following tables are continuous over USB or Ethernet.

The scan rate is defined as (see "Streaming Data Rates" above):

```
ScanRate = SampleRate / NumAddresses
```

Table A.1.7. T7 Stream: Scan rates over various gain, resolution index, channel count combinations. Applies to USB and Ethernet.

	Gain : Range	**Maximum Scan Rate**				**Maximum Sample Rate**
		1 Channel	**2 Channels**	**4 Channels**	**8 Channels**	**>1 Channel**
		[Hz]	[Hz]	[Hz]	[Hz]	[Hz]
Resolution Index = 1*	1 : ±10V	100k	50k	25k	12.5k	100k
	10 : ±1V	100k	4.1k	1.4k	585	8.2k
	100 : ±0.1V	100k	850	315	120	1.7k
	1000 : ±0.01V	100k	N.S.	N.S.	N.S.	N.S.
Resolution Index = 2	1 : ±10V	48k	19.8k	9.0k	4.0k	39.6k
	10 : ±1V	48k	3.6k	1.3k	550	7.2k
	100 : ±0.1V	48k	400	N.S.	N.S.	800
	1000 : ±0.01V	48k	N.S.	N.S.	N.S.	N.S.
Resolution Index = 3	1 : ±10V	22k	9.9k	4.5k	2.4k	19.8k
	10 : ±1V	22k	1.4k	500	225	2.8k
	100 : ±0.1V	22k	N.S.	N.S.	N.S.	N.S.
	1000 : ±0.01V	22k	N.S.	N.S.	N.S.	N.S.
Resolution Index = 4	1 : ±10V	11k	4.9k	2.2k	1.3k	9.8k
	10 : ±1V	11k	1.3k	45	N.S.	2.6k
	100 : ±0.1V	11k	N.S.	N.S.	N.S.	N.S.
	1000 : ±0.01V	11k	N.S.	N.S.	N.S.	N.S.
Resolution Index = 5	1 : ±10V	5500	2.2k	990	630	4.4k
	10 : ±1V	5500	630	23	N.S.	1.3k
	100 : ±0.1V	5500	N.S.	N.S.	N.S.	N.S.
	1000 : ±0.01V	5500	N.S.	N.S.	N.S.	N.S.
Resolution Index = 6	1 : ±10V	2500	1.3k	630	315	2.6k
	10 : ±1V	2500	320	N.S.	N.S.	640
	100 : ±0.1V	2500	N.S.	N.S.	N.S.	N.S.
	1000 : ±0.01V	2500	N.S.	N.S.	N.S.	N.S.
Resolution Index = 7	1 : ±10V	1200	650	315	N.S.	1.3k
	10 : ±1V	1200	220	N.S.	N.S.	440
	100 : ±0.1V	1200	N.S.	N.S.	N.S.	N.S.
	1000 : ±0.01V	1200	N.S.	N.S.	N.S.	N.S.
Resolution Index = 8	1 : ±10V	600	315	N.S.	N.S.	630
	10 : ±1V	600	200	N.S.	N.S.	400
	100 : ±0.1V	600	N.S.	N.S.	N.S.	N.S.
	1000 : ±0.01V	600	N.S.	N.S.	N.S.	N.S.

N.S. indicates settings not supported in stream mode.

* Default stream ResolutionIndex for the T7.

The maximum scan rate will decrease at higher resolution index and range settings simply because analog conversions take longer to complete. Table A.1.5 illustrates how analog conversion times increase at different resolution index and range settings.

Table A.1.8. T7 Stream: Typical noise and interchannel delay values depending on range and resolution index.

Resolution	Peak-to-Peak	Interchannel
Index	**Noise**	**Delay**
	[16-bit counts]	[µs]
Gain/Range: 1/±10V		
1*	±3.0	15/8**
2	±2.0	25
3	±1.5	45
4	±1.0	90
5	±1.0	170
6	±0.5	335
7	±0.5	670
8	±0.5	1,335
Gain/Range: 10/±1V		
1*	±4.5	210
2	±3.0	220
3	±2.0	545
4	±1.5	585
5	±1.0	1,200
6	±0.5	2,415
7	±0.5	2,750
8	±0.5	3,415
Gain/Range: 100/±0.1V		
1*	±12.0	1,040
2	±9.0	2,105
3	**N.S.**	**N.S.**
4	**N.S.**	**N.S.**
5	**N.S.**	**N.S.**
6	**N.S.**	**N.S.**
7	**N.S.**	**N.S.**
8	**N.S.**	**N.S.**
Gain/Range: 1000/±0.01V		
1*	**N.S.**	**N.S.**
2	**N.S.**	**N.S.**
3	**N.S.**	**N.S.**
4	**N.S.**	**N.S.**
5	**N.S.**	**N.S.**
6	**N.S.**	**N.S.**
7	**N.S.**	**N.S.**
8	**N.S.**	**N.S.**

N.S. (Not Supported) indicates settings not supported in stream mode.

* Default stream ResolutionIndex for the T7.

** 15 µs for sample rate <= 60k. 8 µs for sample rate > 60k.

Interchannel Delay:

Interchannel delay is the time between each sample within a scan. For example, say 3 channels are streamed at 1000 scans/second with ResolutionIndex=1 and Range=10. That is a sample rate of 3000 samples/second, so from the table above the interchannel delay is 15 µs. The stream interrupt will fire every 1000 µs, at which time it takes about 5 µs until the 1st channel is sampled, then 15 µs later the 2nd channel is sampled, then 15 µs later the 3rd channel is sampled, and then about 965 µs later the next scan starts.

What if in the above example we wanted the 8 µs delay rather than 15 µs? The sample rate must be greater than 60 ksamples/second for that, so the solution is increase sample rate by scanning more channels (channels can be repeated in the scan list) or scanning faster and discarding the extra data.

The interchannel delay is a fixed time with little jitter, so the known time can be accounted for in user software to adjust phase if those microseconds are important. As an alternative to using the table above, the user can measure interchannel delay on their device by using a scope to look at the SPC timing output described in the Stream Mode section.

Notes:

1. Various software issues need consideration when implementing a feedback loop that executes at the desired time interval. Some considerations are: thread priority, logging to file, updating the screen, and other programs running on the machine.

2. The number of packets used to retrieve stream data depends on the number of data points allowed to accumulate in the stream buffer.

3. Setting the resolution index to 0 (default) in stream mode is equivalent to a resolution equal to 1. The default resolution index in stream mode behaves different than command-response mode.

A-2 Digital I/O [T-Series Datasheet]

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General Info

T-series Digital Input/Output lines information:

Table A2-1. IO Information

Parameter	Conditions	Min	Typical	Max	Units
Low Level Input Voltage		-0.3		0.5	Volts
High Level Input Voltage		2.64		5.8	Volts
Hysteresis Voltage [1]					
---Low to High Transition				1.15	Volts
---High to Low Transition		0.90			Volts
Maximum Input Voltage [2]	FIO	-10		10	Volts
	EIO/CIO/MIO	-6		6	Volts
Output Low Voltage [3][4]	No Load		0.01		Volts
---FIO	Sinking 1 mA		0.55		Volts
---EIO/CIO	Sinking 1 mA		0.15		Volts
---EIO/CIO	Sinking 5 mA		0.75		Volts
Output High Voltage [3][4]	No Load		3.3		Volts
---FIO	Sourcing 1 mA		2.75		Volts
---EIO/CIO	Sourcing 1 mA		3.15		Volts
---EIO/CIO	Sourcing 5 mA		2.6		Volts
Short Circuit Current [3][4]	FIO		6.3		mA
	EIO/CIO/MIO		22.9		mA
Output Impedance [3][4]	FIO		550		Ω
	EIO/CIO/MIO		180		Ω
[1] The "Low Level" and "High Level" input voltage specify input voltage ranges guaranteed to produce the correct logic					

state at any digital input. The "Hysteresis Voltage" represents the voltage where a logic transition will actually occur. Input hysteresis will result in different transition voltages, depending on transition from HIGH to LOW or LOW to HIGH logic states. The overall hysteresis band is ~0.25 volts.
[2] 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 recommend when the device is unpowered, as the voltage will attempt to supply operating power to the device possibly causing poor start-up behavior.
[3] 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 is configured as output-high and shorted to ground, the current sourced by EIO0 into ground will be about 16 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.
[4] It is recommended to use the EIO/CIO digital I/O lines for UART, SPI, I²C, 1-Wire, and other digital communication protocols.

Extended Features

T-series DIO-EF information:

Table A2-2. DIO extended features information

Extended Features	Conditions	Min	Typical	Max	Units
Frequency Output [1]		0.02		5 M	Hz
Counter Input Frequency [2]				5	MHz
Minimum High & Low Time [2]				50	ns
"Interrupt" Total Edge Rate [3][4]	No Stream			70k	edges/s
	T7 Streaming @ 50 kHz			20k	edges/s
	T4 Streaming @ 20 kHz			20k	edges/s
[1] Frequencies up to 40MHz are possible, but they are heavily filtered.					
[2] Hardware counters. 0 to 3.3 volt square wave.					
[3] This is for the "Interrupt" modes. To avoid missing edges, keep the total number of applicable edges on all applicable timers below this limit.					
[4] Excessive processor loading could reduce these limits further.					

Serial Communication

T-series serial communication abilities information is below. T-series devices use 3.3V logic levels and provide 5V output along the VS screw terminal. Some ICs require the same logic level as provided to the chip's VCC line so extra steps may be required to integrate specific sensors.

Table A2-3. Serial communication information

Serial Communication	Conditions	Min	Max	Units
SPI				

Characteristics Clock Frequencies		0.08718	870	kHz
I2C Characteristics				
Clock Frequencies		9.3	472	kHz

A-3 Analog Input [T-Series Datasheet]

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Please see device-specific subsections below.

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

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Please see subsections below.

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

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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.					

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]

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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.

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]

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 ÷ 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.

> Effective Resolution = 16 bits - $\log_2$ (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.

Effective Resolution Vs Resolution Index

Resolution Index	Effective Resolution [bits]	Effective Resolution [µV]	AIN Sample Time [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

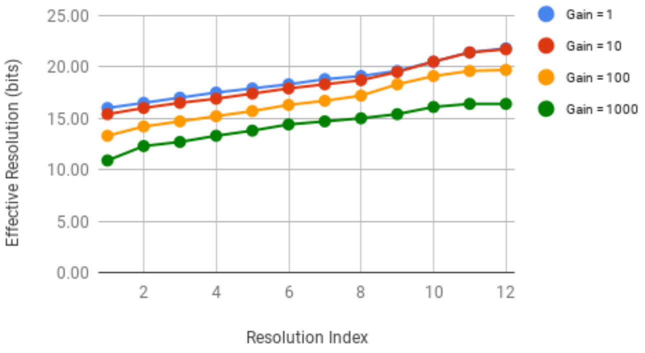

Figure A.3.1.2. T7 analog input effective resolution over various gains and resolution index settings.

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

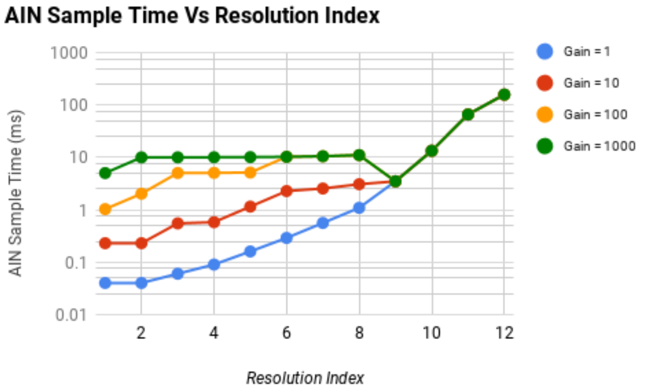

Figure A.3.1.4. T7 AIN sample times for analog inputs over various gains resolution index settings.

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

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:

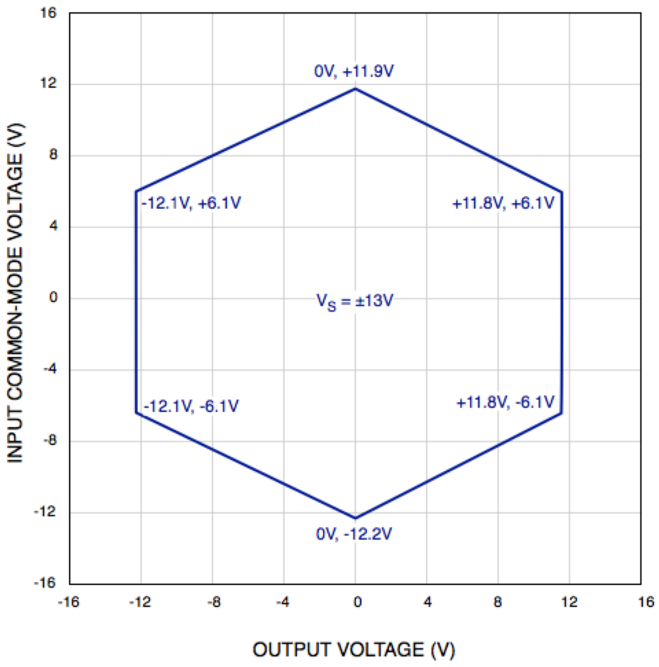
- V_{pos} is 10.0 volts compared to GND
- G=1 (RANGE=±10)

That means:

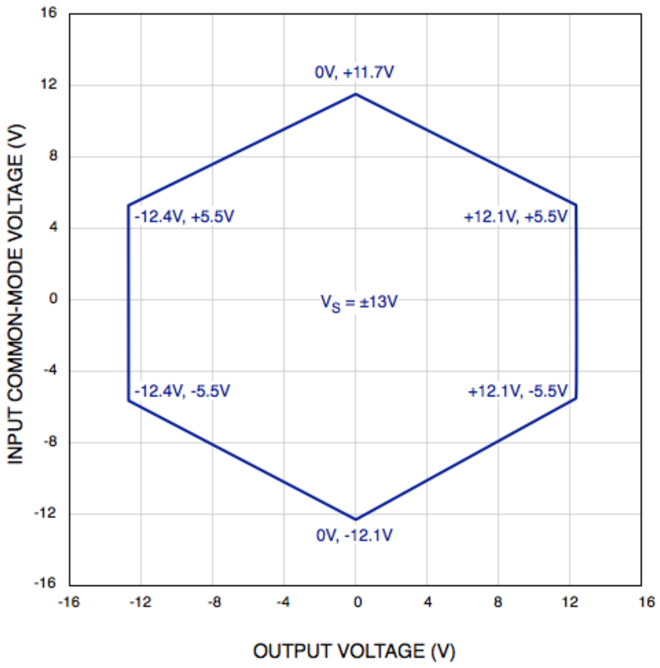
- V_{cm}=5.0 volts,
- V_{diff}=10.0 volts,
- and the expected V_{out}=10.0 volts.

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



A-4 Analog Output [T-Series Datasheet]

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Specifications for analog output channels (DAC0 and DAC1) are shown below.

T4

Table A4-1. T4 DAC Information. All specs at room temperature unless otherwise noted.

	Conditions	Min	Typical	Max	Units
Nominal Output Range [1]	No Load	0.01		4.98	Volts
	@ ±2.5 mA	0.30		4.69	Volts
Resolution			10		Bits
Absolute Accuracy	5% to 95%		±0.15		% FS
			±7.5		mV
Integral Linearity Error				±1	counts
Differential Linearity Error			±0.1	±0.5	counts
Noise [2]			±1		counts
Source Impedance [3]			50		Ω
Current Limit [4]	Max to GND		30		mA
Time Constant			1		µs

[1] 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.

[2] TBD

[3] For currents up to about TBDmA, this source impedance dominates the error due to loading. For example, if you load DAC0 with a 1000 ohm resistor from DAC0 to GND, and set DAC0 to 3.0V, the actual voltage at the DAC0 terminal will be about 3.0*1000/(50+1000) = 2.86V. For currents > TBDmA, you increasingly get added droop due to the ability of the output buffer to drive substantial current close to the power rails.

[4] The output buffer will limit current to about TBDmA and can maintain this value continuously without damage. Take, for example, a 100 ohm resistor from DAC0 to GND, with the internal source impedance of 50 ohms, and DAC0 set to 4.5V. A simple calculation would predict a current of 4.5/(50+100) = 30mA, but the output buffer will limit the current to TBDmA. A simple calculation taking into account only the voltage droop due to the internal 50 ohm resistance would predict a voltage at the DAC0 terminal of 4.5*100/(50+100) = 3.0V, but since the current is limited to TBDmA the actual voltage at DAC0 would be more like 100*0.02 = 2.0V.

T7

Table A4-2. T7 DAC Information. All specs at room temperature unless otherwise noted.

	Conditions	Min	Typical	Max	Units
Nominal Output Range [5]	No Load	0.01		4.99	Volts
	@ ±2.5 mA	0.25		4.75	Volts
Resolution			12		Bits
Absolute Accuracy	5% to 95% FS		±0.06		% FS
Integral Linearity Error			±1.5	±2	counts
Differential Linearity Error			±0.25	±0.5	counts
Noise [6]			±100		µV
Source Impedance [7]			50		Ω
Current Limit [8]	Max to GND		20		mA
Time Constant			4		µs
[5] 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.					
[6] With load, the noise increases if operating too close to VS. With a 1000 ohm load, noise increases noticeably at 4.4V and higher. With a 330 ohm load, noise increases noticeably at 3.7V and higher. With a 100 ohm load, noise increases noticeably at 2.7V and higher.					
[7] For currents up to about 8mA, this source impedance dominates the error due to loading. For example, if you load DAC0 with a 1000 ohm resistor from DAC0 to GND, and set DAC0 to 3.0V, the actual voltage at the DAC0 terminal will be about 3.0*1000/(50+1000) = 2.86V. For currents > 8mA, you increasingly get added droop due to the ability of the output buffer to drive substantial current close to the power rails.					
[8] The output buffer will limit current to about 20mA and can maintain this value continuously without damage. Take, for example, a 100 ohm resistor from DAC0 to GND, with the internal source impedance of 50 ohms, and DAC0 set to 4.5V. A simple calculation would predict a current of 4.5/(50+150) = 30mA, but the output buffer will limit the current to 20mA. A simple calculation taking into account only the voltage droop due to the internal 50 ohm resistance would predict a voltage at the DAC0 terminal of 4.5*100/(50+100) = 3.0V, but since the current is limited to 20mA the actual voltage at DAC0 would be more like 100*0.02 = 2.0V.					

A-5 General Specs [T-Series Datasheet]

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All specs at room temperature unless otherwise noted.

Power Supply Input

The following table shows the supply voltage that is required. The USB hub or 5V USB adapter in use should fall within the acceptable range.

Table A5-1.

Parameter	Condition	Min	Typical	Max	Units

Supply Voltage		4.75		5.25	Volts
Supply Current	T7, No connected loads [1]	4	250	290	mA
	T4, No connected loads [1]		210		mA
[1] Supply current will vary, depending on communication and enabled functionality. See Power Consumption section below for more details. Total continuous supply current should be kept to 500 mA or less.					

VS Outputs

The following table provides specifications for the VS outputs.

Table A5-2.

Parameter	Condition	Min	Typical	Max	Units
Voltage [1]		4.75		5.25	Volts
Max Current	500 mA - Supply Current		200		mA
[1] VS voltage is the same as the power supply voltage.					

System Clock

Table A5-3.

Parameter	Condition	Min	Typical	Max	Units
Clock Error	~ 25 °C			±20	ppm
	-10 to 60 °C			±50	ppm
	-40 to 85 °C			±100	ppm

Physical

Table A5-4.

Parameter	Condition	Min	Typical	Max	Units
USB Cable Length			2	5	meters
Operating Temperature		-40		85	°C
Screw Terminal Wire Gauge			26	14	AWG
Mounting Screws	wood screw sizes	#4	#6	#8	
Enclosure Screws (x6)	PH1 pan head		#4-20 x 5/8"		Phil #1

Power Consumption

At this time USB and Core speed are not intended for user level control, but have been included in the following table to show the capabilities of the device. The values shown are typical.

Table A5-5. T4 Power Consumption

Core Speed	Eth [1]	Eth Linked	LEDs	USB [1]	USB Linked	Draw (mA)	Typical Deviation (%)
80M	ON	Yes	ON	ON	Yes	210	±4
80M	ON	Yes	ON	ON	No	195	±4
80M	ON	No	ON	ON	Yes	170	±4
80M	ON	No	OFF	ON	Yes	TBD	±10
80M	ON	No	OFF	OFF	No	TBD	±10
20M	ON	No	OFF	OFF	No	TBD	±20
2M	OFF	No	OFF	OFF	No	TBD	±20
250k	OFF	No	OFF	OFF	No	TBD	±33
[1] Ethernet and USB require that the core be running at least 20MHz.							

Table A5-6. T7 Power Consumption

Core Speed	Eth [1]	Eth Linked	AINs	WiFi	WiFi Linked	LEDs	USB [1]	Draw (mA)	Typical Deviation (%)
80M	ON	Yes	ON	ON	Yes	ON	ON	280	+/- 4
80M	ON	Yes	ON	ON	No	ON	ON	280	+/- 3
80M	ON	Yes	ON	OFF	No	ON	ON	250	+/- 4
80M	ON	No	ON	OFF	No	ON	ON	200	+/- 5
80M	OFF	No	ON	OFF	No	ON	ON	170	+/- 4
80M	OFF	No	OFF	OFF	No	ON	ON	140	+/- 4
80M	OFF	No	OFF	OFF	No	OFF	ON	94	+/- 11
80M	OFF	No	OFF	OFF	No	OFF	OFF	86	+/- 9
20M	OFF	No	OFF	OFF	No	OFF	OFF	28	+/- 18
2M	OFF	No	OFF	OFF	No	OFF	OFF	10	+/- 20
250k	OFF	No	OFF	OFF	No	OFF	OFF	6	+/- 33
[1] Ethernet and USB require that the core be running at least 20MHz.									

200µA and 100µA Current Sources - T7 Only

Table A5-7.

Parameter	Condition	Min	Typical	Max	Units
Accuracy vs. Cal Value [1]	~ 25 °C		±0.1	±0.2	%
Accuracy vs. Nominal [1]	~ 25 °C			±5	%
TempCo 200UA [2]	~ 25 °C				ppm/°C
TempCo 10UA [2]	~ 25 °C				ppm/°C
Maximum Voltage			2.0V less than VS		volts
[1] First spec is the accuracy compared to the value stored during calibration. The second spec is the accuracy compared to the nominal value (e.g. 200.0 µA for the 200UA source).					
[2] Tempco varies strongly with temperature. See the charts in12.0 200uA and 10uA.					

VM+ and VM- (T7 Only)

Table A5-8.

Parameter	Condition	Min	Typical	Max	Units
Typical Voltage	No-load		±13		volts
	@ 2.5 mA		±12		volts
Maximum Current			2.5		mA