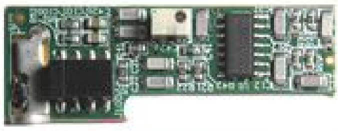
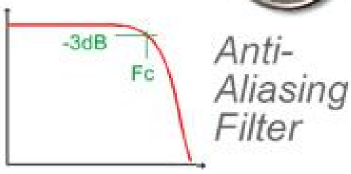
MODEL i500 ANTI-ALIASING LOW PASS FILTER

The i500 anti-aliasing low pass filter provides the following features:





- 8-Pole analog low pass butterworth filter daughterboard, ideal for anti-aliasing
- End user installs between 1 and 6 filter daughterboards onto each i423 card, one daughterboard per channel
- Maximum of 35 filtered channels per system
- Sold in packages of two filters per product, each is 1.7 x 0.6 inches (4 x 2 cm)
- i500 analog filter provides extremely low ±0.01dB maximum passband ripple for Fin/Fc ≤ 0.5. If one uses further oversampling, digital filtering and desampling; then passband ripple is ±0.002dB for Fin/Fc ≤ 0.8 due to the accuracy of a 30-pole digital filter.
- i500 analog filter provides stopband attenuation of ≥ 76dB for Fin/Fc ≥ 3
- Signal first passes through i423 signal conditioning amplifier before reaching i500 analog filter; therefore, one can attach directly to the following sensors: Voltage, Thermocouple, Thermistor, RTD, Load Cell, Strain Gage, Current, Resistance, Accelerometer
- 4 different filter products, each with different cut off frequencies: 380Hz, 1KHz, 3.3KHz, 10KHz. However, further digital processing provides other cutoff frequencies lower than these. For example, with an i500 Fc=1KHz analog filter one can digitize at **ANY** sample rate less than 2Ks/sec/channel and have a DIGITAL low pass filter provide anti-aliasing.
- See Also:
  - Product Summary
  - List of Products
  - Specifications
  - Software Set Up

What is an Anti-Aliasing Filter?

For a summary of aliasing and why you might need an AFS filter, click here.

i500 Product Summary

The instruNet i4xx card cage is available with 4, 8, 12 or 16 slots. The first slot is used to house the i41x interface card and the 2nd slot is used for the i43x a/d measurement card. One can populate the remaining slots with i423 cards. The i423 provides 6 signal conditioning amplifiers, one for each channel. These can measure voltages, and car also attach directly to common sensors such as thermocouples and strain gages. Each channel on the i423 includes a socket that attaches to a tiny optional 4 x 2 cm daughterboard. This is held in place with one bolt and is installed by the end user. There are four different i500 filter daughters to choose from, each with a different cutoff frequency. Yet optional further digital low pass filtering provides lower cutoff frequencies. For example, one can digitize at 100s/sec/channel with the Fc=1KHz i500 analog filter and digitally filter at Fc=38.5Hz to get anti-aliased 100s/sec/ch data. Internally the system would digitize at ≥ 6Ks/sec/ch and do digital processing to calculate very accurate 100s/sec/ch data. This digital processing is done in the background and the end user only needs to set one software parameter called "Auto Afs" to enable it.

Analog & Digital Filtering via Auto Afs

There are two methods of implementing anti-aliasing with instruNet. One method is to oversample, digitally filter, and then desample (Auto Afs ON). The other method involves no oversampling and no digital filtering (Auto Afs OFF). The end user enables Auto Afs with a parameter in the Record Setup dialog box. Both methods result in aliased free data. Auto Afs ON has several advantages:

- digital processing provides **ANY** low pass cutoff frequency (Fc) less than 77% of the i500 analog cutoff frequency; where sample rate is 2.6 times this Fc
- lower passband ripple
- passband is larger with respect to sample rate (i.e. sharper roll-off from digital filter)

The two Auto Afs options are described below:

1) Auto Afs OFF (no digital filtering)

The table below summarizes Auto Afs OFF (no digital filtering, no oversamping). "Sample Rate" refers to the number of points digitized per channel in order to attenuate at least 76dB at the nyquist frequency (which is what is needed to obtain fully anti-aliased data). "Passband (Hz)" is the frequency range of the resulting data with ≤ ± 0.01dB of ripple (deviation from gain of 1.0), where Fin/Fc ≤ 0.5. "Max # of Channels" is the maximum number of channels tha one can digitize at this sample rate, as limited by the i423 maximum aggregate sample rate, which is documented here. Also, the i312 power supply supports up to 35 quantity i500 filtered channels in a card cage with six i423 cards

#i500-380Hz	#i500-1KHz	#i500-3300Hz	#i500-10KHz	Parameter
380	1,000	3,300	10,000	i500 Analog Filter Fc (Hz)
2,304	6,000	19,800	60,000	Sample Rate (s/sec/ch)
1,152	3,000	9,900	30,000	Nyquist (Hz)

#i500-380Hz	#i500-1KHz	#i500-3300Hz	#i500-10KHz	Parameter
190	500	1,650	5,000	Passband (Hz)
35	13	4	1	Max # of Channels

2) Auto Afs ON (oversample, digital filter, desample)

The below table summarizes operation when the Auto Afs feature is ON (i.e. oversample, digitally filter, desample). "End User Data" refers to the largest sample rate for aliased-free data and is set by the end user in the Sample Rate field within the Record Setup dialog. The system internally samples faster (oversample). The Nyqust frequency is 50% of the End User sample rate and the nyquist is 130% of the digital filter cutoff frequency (Digital Filter Fc). The resulting Passband is 90% of the Digital Filter Fc. The ratio of the internal oversample rate and the end user sample rate is an integer; therefore not all sample rates are feasible. Subsequently, if Auto Afs does not engage, try a slightly different sample rate.

#i500-380Hz	#i500-1KHz	#i500-3300Hz	#i500-10KHz	Parameter
380	1,000	3,300	10,000	i500 Analog Filter Fc (Hz)
≤ 777	≤ 2,022	≤ 6,673	≤ 20,222	End User Data (s/sec/ch)
≤ 388	≤ 1,011	≤ 3,337	≤ 10,111	Nyqust (Hz)
≤ 299	≤ 778	≤ 2,567	≤ 7,778	Digital Filter Fc
≤ 269	≤ 700	≤ 2,310	≤ 7,000	Passband (Hz)
35	13	4	1	Max # of Channels

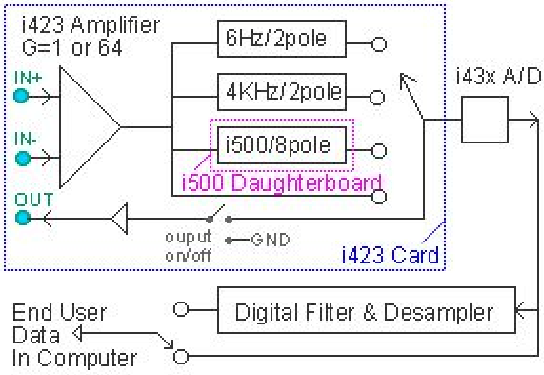
List of Analog Filter Products

Below is a list of products, which are sold in packages of 2 filters per package. Each digitized channel, attached to a sensor, supports one filter daughterboard.

Product Model #	Fc Freq	Description
#iNet-500-380Hz	380 Hz	Package of 2 analog filter daughterboards (supports 2 independent channels), 8-Pole, Butterworth
#iNet-500-1KHz	1 KHz	"
#iNet-500-3300Hz	3.3 KHz	"
#iNet-500-10KHz	10 KHz	"

Signal Path

The diagram to the right shows the signal path when working with the i500 analog filter. The signal first passes through the i423 low noise amplifier which amplifies the signal with a gain between 1 and 64. This gain is set by the end user via the Measurement Range parameter in the Hardware channel setting area. The signal then passes through one of the following: i500 8-pole analog filter, internal i423 **6**Hz/2pole filter, internal i423 **4**KHz/2pole filter, or no analog filter. The filter is selected by the end user with the Low Pass Filter parameter in the Hardware channel setting area. After this, the signal is optionally further processed with a 30-pole digital filter and desampler. To enable this digital filter, one must set the end user Sample Rate parameter (samples-per-second-per-channel) to a value that is less than 2 times the i500 Fc frequency (e.g. < 2Ks/sec/ch with i500-1KHz) and then set the Auto Afs parameter in the Record Setup dialog box to **On**. To verify that it is set up properly, select Digitize Channels Report under Setup in the menubar.

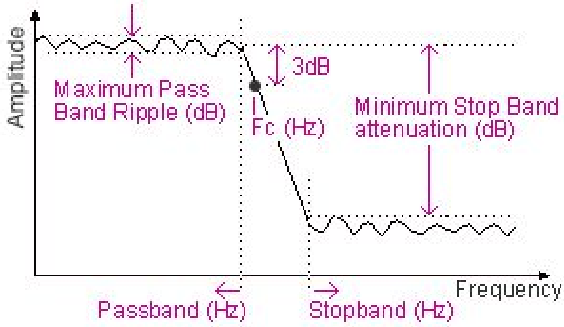


Filter Output Available Electrically at Hd44 Connector Pin

Notice the above "Signal Path" illustration has an **OUT** pin along the left edge. Filter outputs are available electrically at i423 Hd44 connector pins 17 through 22. These are short circuit protected against ±12Volts power on or off; have a drive capability of 3mA and 10K pF via an internal operational amplifier; and have a maximum output working voltage of ±5Volts. These buffered outputs are normally off (0Volts output), and remain off until the end user has turned them on. This can be done by setting Channels #17...22 to ON from within instruNet World software (i.e. click on i423 Ch17..22 in NETWORK page and set Amplifier Output to ON), or writing ON (1=on, 2=off) to those channel addresses via software. The advantage of keeping them off is they are less likely to couple into input signals within the end user's cable. One can use the output pin without digitizing by running the instruNet software and setting the following parameters, as described here (except for enabling for digitize).

Low Pass Filter Theory of Operation

The figure to the right describes a low pass filter. In summary, a low pass filter passes low frequencies and attenuates high frequencies. The transition from the passband to the stopband occurs in the vicinity of the cutoff frequency, commonly referred to as "Fc" in units of Hz. It is here that the signal is attenuated 3dB, which corresponds to a 70% attenuation in amplitude voltage. For example, if you input a 1KHz 10Vpp (volts peak-to-peak) sine wave into a filter with a 1KHz Fc, then the output will be 1KHz 7Vpp. Power is porportional to the square of the Voltage, therefore a 70% attenuation in voltage is associated with a 50% (70% * 70%) attenuation in power.



Passband Ripple

In the passband, a perfect filter has a gain of 1.0, which is the same as 0 dB. Yet real filters vary slightly from 1.0 and this deviation is sometimes referred to as "passband ripple", as illustrated in the above figure. The maximum ripple is specified in the below table for both the i500 analog filter and a 30-pole digital filter which might follow the i500 analog filter.

Frequency (Fin/Fc)	i500 ANALOG Filter Max Ripple (Auto Afs OFF, 8-poles)	DIGITAL Filter Max Ripple (Auto Afs ON, 30-poles)
0.9	-8.0 ± 4.0% (-0.7 ±0.4 dB)	-0.1 ± 0.03% (-0.008 ±0.003 dB)
0.8	-1.4 ± 0.8% (-0.12 ±0.08 dB)	±0.02% (±0.002 dB)
0.5	±0.1% (±0.01 dB)	±0.02% (±0.002 dB)
≤ 0.3	±0.05% (±0.005 dB)	±0.02% (±0.002 dB)

For example, if one inputs a 400Hz sine wave with amplitude 1Vpp (Volts between top and bottom of sine, peak-to-peak) into an i500-1KHz filter, then the digitize signal would be a 400Hz sine with an amplitude between 0.999Vpp and 1.001Vpp (i.e. 0.1% ripple). And in the frequency range ≤ 300Hz; the output would be between 0.9995Vpp and 1.0005Vpp.

A typical 30-pole digital filter often has a variation less than 1 LSB (least significant bit) of the A/D (analog to digital) converter, which means it is close to perfect. The reason digital filters are more accurate is the numerical coefficients used to implement them are accurate to 7 decimals (e.g. 0.00001%) and the resistors and capactors in analog filters are typically accurate to 1%.

A potentiometer on the i500 is set at the factory and is used to tune errors from resistors and capacitors. This works to some extent, yet not to the point of making a perfect filter. One reason of which is that resistors and capacitors vary slightly with temperature and with time ("stability"). Therefore setting a potentiometer in the factory while the filter is at one temperature will see a little variation later when the filter in the field is at a slightly different temperature.

All i500 analog filter daughterboards uses NPO/COG capacitors that are accurate to approximately 1% in initial value and drift very little with temperature (e.g. 30ppm/C); and are therefore very accurate.

A common problem in filter design is lower frequency filters (e.g. < 100Hz Fc) need larger capacitors and larger capacitors are often not available in accurate and stable materials. The i500 filter product family deals with this by providing the i500-380Hz lowest Fc filter (which uses accurate capacitors) and then provides lower Fc's to the end user with digital filtering and desampling that follows the analog filtering. Therefore, the end user can enjoy extremely accurate data (e.g. < ±0.002 dB ripple) at lower Fc frequencies.

Stopband Attenuation

The stopband involves frequencies in excess of the cutoff frequency. Stopband minimum attenuation for both the i500 8-pole analog filter and 30 pole digital filter (which might follow i500) are shown in the below table.

Frequency (Fin/Fc)	i500 ANALOG Filter Min Attn (Auto Afs OFF, 8-poles)	DIGITAL Filter Min Attn (Auto Afs ON, 30-poles)
1.0	70% (-3 dB)	70% (-3 dB)
1.1	45% (-7 dB)	4% (-28 dB)
1.2	25% (-12 dB)	0.3% (-50 dB)
1.3	14% (-17 dB)	0.02% (-72 dB)

Frequency (Fin/Fc)	i500 ANALOG Filter Min Attn (Auto Afs OFF, 8-poles)	DIGITAL Filter Min Attn (Auto Afs ON, 30-poles)
1.5	5% (-26 dB)	< 0.01% (-80 dB)
2.0	0.5% (-46 dB)	< 0.01% (-80 dB)
≥ 3.0	< 0.015% (-76 dB)	< 0.01% (-80 dB)

For example, if you digitize at 200s/sec/channel (100Hz nyquist) with a i500-1KHz analog filter and Auto Afs enabled, then the instruNet system will internally digitize faster (e.g. ≥ 6Ks/sec/ch), pass the signal through the i500 analog filter (Fc = 1KHz), run a 30-pole digital filter (Fc = 76Hz) and provide > 72dB of attenuation at the 100Hz nyquist frequency (1.3 * 76 Hz = 100 Hz). In this example, one would have < ±0.02% (±0.002 dB) passband ripple for frequencies < 61Hz (0.8 * 76Hz = 61Hz).

Specifications

Specification	i500 ANALOG Filter	DIGITAL Filter
Type	8-Pole Butterworth	≥ 30-Pole IIR Butterworth
Cut-off Freq.	380, 1K, 3.3K, or 10KHz	0.01 Hz to 10KHz
Fc Freq Accuracy	±2%	±0.01%
Fc Freq Stability	±0.01%/°C	n/a
Stopband Attn	see table	see table
Passband Ripple	see table	see table
Max Noise	-90 dB	-120 dB
Passes DC	yes	yes
DC Voltage Gain	±0.02% (±0.002 dB)	±0.02% (±0.002 dB)
Power Consumed	8mA @ -12V, 8mA @ +12V	n/a
Design	Op Amp (not switched IC)	Digital
Size	1.7x0.6 inches (4.3x1.6cm)	n/a

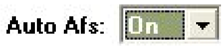
i500 Filter Software Set Up

The following steps are required to set up an i500 low pass filter:

1. Physically install your i500 hardware daughterboards, as described here.
2. Make sure you are working with instruNet DLL file "iNet32.dll" version ≥ 3.3.4.4. To check your version, run instruNet World software and select ABOUT in the HELP menu. To upgrade to a newer iNet32.dll file, free of charge, click here.
3. Run instruNet World software and set up your channels without low pass filtering. Digitize in the Record page and make sure your channels are set up properly. Save your settings by pressing the SAVE button in the NETWORK page (not the RECORD page).

4. For each channel with an i500 filter, set the Low Pass Filter (Hz) parameter to "i500-*xx* Hz", as shown to the right. This will cause the signal to pass through the 8-pole i500 analog filter after being amplified by the i423 signal conditioning amplifier. You need to do this independent of whether or not you are enabling Auto Afs.

5. Set the Auto Afs parameter in the Record Setup dialog box to **On**, as shown to the right. This will enable the more accurate digital processing, if possible. If it is not possible (e.g. your requested sample rate is too high), then the digital processing will not occur. It is recommended that this always be ON when working with i500 filters.



6. Turn off Integration for all channels that are digitizing. In other words, set Integration to 0 seconds, as shown to the right. This is very important since Integration directly reduces maximum oversampling sample rate, as noted here.

7. Set your Sample Rate (samples-per-second-per-channel) in the Record Setup dialog box. This is not the oversample rate. This is the sample rate of the data that is returned to the end user. The end user never sees the oversampled data.

8. Select Digitize Channels Report under Setup to see if your channels are set up as desired. Focus on the "Aliasing Occurs Here" column. You want to see "No Aliasing". If you do not, then your anti-aliasing is not set up properly; in which case, see Debugging below.

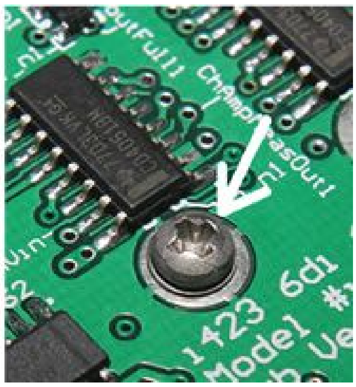
9. Try Digitizing in the Record page and view your resulting waveforms. For details on how to do this, click here. If you want to do more serious testing with a function generator, click here.

10. Press the SAVE button in the NETWORK page (not RECORD page) to save your settings.

11. If you want to further test and/or debug, click here.

i500 Filter Hardware Installation

The i500 filter daughterboard bolts to the i423 card, one daughterboard per channel, as shown in the below photo. When installing the i500, make sure the 2-56 bolt is snug. Obviously, one needs to remove the i423 card before installing the i500 daughterboard. The i423 sockets are labeled "Ch 1", "Ch3", etc.



i500 Considerations

- After you turn Auto Afs **On**, the system checks if it can internally digitize at a rate faster than the end user requested sample rate. If so, it oversamples (internally digitizes faster), digitally filters, and then desamples. If not it digitizes normally. To learn more about this for a specific setup, select Digitize Channels Report under Setup.

- The maximum aggregate (all channels) sample rate on the i423 is approximately 80ks/sec when integration is set to 0 seconds. This varies slightly with smaller voltage ranges, as noted here. This limits the number of channels you can digitize when oversampling, digital filtering, and desampling. The internal oversample rate cannot exceec this ~80ks/sec aggregate limitation. The end user waveform can be at any sample rate less than this and is set in the Record Setup dialog box via the end user data Sample Rate parameter. The Digitize Channel Report shows the oversample rate in the "Oversample Rate" column; and shows the end user sample rate in the "Sample Rate" column. 80Ks/sec aggregate means that you can digitize 2 channels at 40K each, 3 at 26K each, 4 at 20K each, etc.

- After turning **On** the Auto Afs parameter, the system will oversample, digital filter, and desample if possible. To see if this is actually happening (i.e. auto afs is engaging), select Digitize Channels Report and look for "Auto afs implemented OK" above the table. If you see this comment, then the 30-pole digital filter is working to return very accurate data.

- One can turn **On** the Auto Afs parameter with no i500 analog filters installed, and this will cause the system to still oversample, digitally filter, and desample; to reduce aliasing. To help further reduce aliasing, one can turn ON the i423 internal 4KHz/2pole or 6Hz/2pole analog Low Pass Filter. To see the effect of your set up, select Digitize Channels Report under Setup.

- In order to digitize with the i500 analog filter, you need an i423 card, an i43x a/d card, and an i41x interface card. The later two cards (i41x, i43x) are included with the i555 product. One might also want an i51x wiring box affixed to the i423 card.

- After pressing the START digitize button, the digital filter outputs might appear erradict for a short duration (e.g. 50mSec with Fc=1KHz); due to not having past data.

- Analog and digital filters often induce delays. To see this, digitize the same signal with 2 channels (e.g. jumper wire connects two inputs), where one channel has an i500 filter and the other does not (or turn one i500 off). Then look at both waveforms in the Record page and notice one is horizontally shifted with respect to the other.

- Analog Trigger initiates the start of a digitization and looks at the waveform after the analog filter yet before before any digital filters.

- One cannot simultaneously digitize from voltage input channels and output to d/a channels while doing Auto Afs.

- The Auto Afs digital filter is not related to the end user controlled Digital Filters. These two operate independently and in series.

i500 Debugging

- Read the above Considerations.

- After setting up your channels for anti-aliasing, as described here, select Digitize Channels Report under Setup in the menubar to learn about your setup. Make sure that the "Alias Occurs Here" column shows "No Aliasing". If you do not see this, then check each step in Software Setup. Do you have Integration turned off for channels enabled for digitizing (you want it set to 0 seconds)? Did you remember to enable your i500 Analog Filter? Are you digitizing from channels that have an i500 analog filter daughterboard physically installed?

- When Auto Afs is engaged, the ratio of the internal oversample rate and the end user data sample rate is always an integer; therefore not all sample rates are feasible. Subsequently, if Auto Afs does not engage, try a slightly different sample rate.

- When doing Auto Afs, there is an end user data sample rate and an over sample rate. Lets call the ratio between these two *X*. Also, for each channel, there is an end user data RAM buffer and an over sample RAM buffer of size (Points-per-Scan) and (Points-per-Scan * *X*) respectively. Recall that end user Points-per-Scan and Sample Rate (s/sec/ch) are set in the Record Setup dialog box. If Points-per-Scan is big (e.g. ≥ 100M) then your over sample RAM buffer will be very big and you might get an "out of memory" alert when you start digitizing. To see the over sample rate, refer to the "AFS Oversample Rate" column in the Digitize Channels Report .

- If the i2x0 controller SWITCHING parameter is set to ACCURATE (instead of FAST), then the controller will switch between channels more slowly and maximum total aggregate sample rate is ~30ks/sec instead of ~166Ks/sec. To access the SWITCHING parameter in instruNet World software, press the SETUP button in the RECORD page and then press the TIMING button. To access the the SWITCHING parameter in DASYLab software, press the SET GLOBAL INSTRUNET PARAMETERS button within the voltage input icon. The default setting is ACCURATE in DASYLab and FAST in all other cases.

- Input a sine wave (e.g. from an external function generator) at different frequencies while digitizing anti-aliased data and note digitized amplitude as a function of frequency. The sine should appear in the Record page if its frequency is less than approximately 40% of the sample rate; and should appear as 0 Volts DC if its frequency is higher. Try this again with the i500 Low Pass Filter turned off and note that higher frequencies now appear fully intact, or they appear at a lower frequency (i.e. they alias) yet at an amplitude similar to the input signal.

  Many of the older (≤ 2010 era) low cost (≤ $300) function generators output several milliVolts of both low and high frequency noise/harmonics, and this is added to the intendend output signal. If you filter out the intended signal and then look at the result, you might see this "error" signal that is coming from your (deficient) function generator. The lowest cost ≥ 2011 Rigol function generators provide a clean signal at reasonable cost.

Digitize Channels Report

After setting up the system, one can easily learn more about bandwidth and aliasing by selecting "Digitize Channels Report" under Setup in the menubar, as illustrated to the right. This prints a table that describes channels enabled for digitizing.

Auto Afs Engage Indicators

If Auto Afs is turned On and the setup is sufficient for oversampling, digital filtering, and desamping; then "Auto afs implemented OK" will be shown above the digitize channel report table and "Afs On" will be shown to the right of the PRINT button in the RECORD page while digitizing. These two indicators communicate that auto afs has engaged and that the 30-pole digital filter is returning very accurate data.

Channel Report from DASYLab Software

To access this report from DASYLab software, click OPEN INSTRUNET WORLD WINDOW from within the voltage inpu icon; and then select "Digitize Channels Report" under Setup.

Digitize Channel Report Columns

The columns of the Digitize Channel Report table are described below.

Column	Description
Sample Rate (s/sec)	Sample Rate per channel in samples-per-second-per-channel units. This is end user data, after any oversampling/filtering/desamping.
Nyquist (Hz)	Bandwidth of end user data, in units of Hertz. This is always 50% of the sample rate.
End User Bandwidth (Hz)	Bandwidth of end user data, after it has been filtered. If Auto Afs is ON, this is 90% of the Digital Filter cutoff frequency (Fc).
Aliasing Occurs Here	If there is no aliasing, then "No Aliasing" is shown; otherwise, the frequency at which aliasing begins is displayed.
Analog Bandwidth (Hz)	Bandwidth of signal conditioning amplifier and analog filter.
Analog Filter (Hz)	If an analog filter is enabled, the cutoff frequency is shown; otherwise, "Off" is displayed.
AFS Digital Filter Passband (Hz)	If Auto Afs is ON, this is 90% of the Digital Filter Fc. It is also the maximum frequency with a tiny amount of passband ripple.
AFS Oversample Rate (s/sec)	If Auto Afs is ON, this is the internal oversample rate in units of samples-per-second-per-channel.
Integration Time (mSec)	Amount of Integration time in units of mSec. If integration is off (i.e. 0 sec) then "No Integ" is displayed.

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