Considerations related to sampling rate and filter settings

1 SUMMARY

In Sensonor's STIM-products the sampling rate and low-pass filter bandwidth can be independently configured. Care should be taken when setting these in order to avoid problems of folding and thereby increased noise and other possible problems related to aliasing of signals.

This document addresses issues related to choice of sampling rate and low-pass filter in STIM-products and give recommendation to certain combinations.

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2 AVAILABLE OUTPUT SAMPLING RATES

The individual sensor-channels in STIM are continuously and synchronously sampled internally at 2000 samples/s regardless of the selected output sampling rate.

When the output unit is set to “Angular Rate” for gyros or “Acceleration” for accelerometers or inclinometers, the output sampling rate is achieved by transmitting only every n^{th} sample, see Table 2-1:

Table 2-1: Available output sampling rates

Output sampling rate	Transmitting every n^{th} samples, where n =
2000 samples/s	1
1000 samples/s	2
500 samples/s	4
250 samples/s	8
125 samples/s	16

3 AVAILBALE LOW-PASS FILTERS

In STIM there are 5 different low-pass filters that freely can be chosen regardless of the configured sample rate. The filters are of CIC-type. Table 3-1 contains some key properties of the available filters. The filter characteristics can be found in chapter 7.

Table 3-1: Available low-pass filters

Bandwidth (-3dB)	1.notch	2.notch	3.notch	4.notch	5.notch
16Hz	63Hz	125Hz	188Hz	250Hz	313kHz
33Hz	125Hz	250Hz	375Hz	500Hz	625Hz
66Hz	250Hz	500Hz	750Hz	1000Hz	1250Hz
131Hz	500Hz	1000Hz	1500Hz	2000Hz	2500Hz
262Hz	1000Hz	2000Hz	3000Hz	4000Hz	5000Hz

4 COMBINATION OF OUPUT SAMPLING RATES AND LOW-PASS FILTERS

To achieve the best noise performance, the low-pass filter must be selected so that all signals at frequencies above half the sampling frequency (the Nyquist frequency) are sufficiently attenuated.

To obtain the noise performance as specified in the datasheet, a filter where half the sampling rate coincides with one of the notches of the filter, must be chosen. Signals above the Nyquist frequency will then be attenuated by 40 dB or more. In special cases, a filter with lower cut-off frequency may be required. Table 4-1 summarizes the recommended combinations.

In general, reducing the filter bandwidth will reduce the gyro noise level. Hence the smallest bandwidth compatible with the signal frequency should always be selected, provided that the associated group delay can be tolerated.

Table 4-1: Recommended combinations of output sampling rate and low-pass filter bandwidth

	Low-pass filter bandwidth (-3dB) group delay				
Output sampling rate	16Hz 23.9ms	33Hz 12.2ms	66Hz 6.4ms	131Hz 3.4ms	262Hz 2ms
2000 samples/s	OK	OK	OK	OK	OK
1000 samples/s	OK	OK	OK	OK	Possible
500 samples/s	OK	OK	OK	Possible	Avoid
250 samples/s	OK	OK	Possible	Avoid	Avoid
125 samples/s	OK	Possible	Avoid	Avoid	Avoid

5 USING OTHER OUTPUT UNITS

By using any of the other output units than “Angular Rate” for gyros or “Acceleration” for accelerometers or inclinometers, the concerns as pointed out in section 4, can be disregarded.

Table 5-1 and Table 5-2 describes the alternative output units for gyros and accelerometers/inclinometers respectively.

Note that using any of the output units described in Table 5-1 and Table 5-2, the frequency response will be affected compared to filter characteristics outlined in section 7.

Table 5-1: Implemented functions for gyro output units

Function	Description of function	Equation	Output unit
Incremental	Adds all internal samples between two transmissions multiplied by the time between internal samples	$Incremental = \sum_{i=1}^{n} AngularRate_i \cdot \frac{1}{2000} s$ n = 2000 / sample rate	[°]
Average	Calculates the average of the internal samples between two transmissions	$Average = \frac{1}{n} \cdot \sum_{i=1}^{n} AngularRate_i$ n = 2000 / sample rate	[°/s]
Integrated	Adds all internal samples multiplied by the time between internal samples since start-up / last reset. Note that the result takes values in a specific interval as described in datasheet for the specific STIM-product and will naturally wrap-around with no error-message indication in the Status-byte	$Integrated = \sum_{i=1}^{n} AngularRate_i \cdot \frac{1}{2000} s$ n = internal samples (at a rate of 2000 samples/s) since start-up or last reset)	[°]

Table 5-2: Implemented functions for accelerometer/inclinometer output units

Function	Description of function	Equation	Output unit
Incremental	Adds all internal samples between two transmissions multiplied by the time between internal samples and converted to [m/s]	$Incremental = k_0 \cdot \sum_{i=1}^{n} Acceleration_i \cdot \frac{1}{2000} s$ k_0 = 9.80665 m/s^2/g n = 2000 / sample rate	[m/s]
Average	Calculates the average of the internal samples between two transmissions	$Average = \frac{1}{n} \cdot \sum_{i=1}^{n} Acceleration_i$ n = 2000 / sample rate	[g]
Integrated	Adds all internal samples multiplied by the time between internal samples since start-up / last reset. Note that the result takes values in a specific interval as described in datasheet for the specific STIM-product and will naturally wrap-around with no error-message indication in the Status-byte	$Integrated = k_0 \cdot \sum_{i=1}^{n} Acceleration_i \cdot \frac{1}{2000} s$ k_0 = 9.80665 m/s^2/g n = internal samples (at a rate of 2000 samples/s) since start-up or last reset	[m/s]

6 COMMENT TO STIM202 STANDARD CONFIGURATION

From Table 4-1 it can be seen that the standard configuration of STIM202 (1000 samples/s and LP-filter bandwidth = 262Hz) does not conform to Table 4. The choice of this configuration is related to achieving the lowest possible group delay. If a larger group delay can be tolerated, the recommendations set out in Table 4-1 should be chosen.

7 LOW-PASS FILTER CHARACTERISTICS

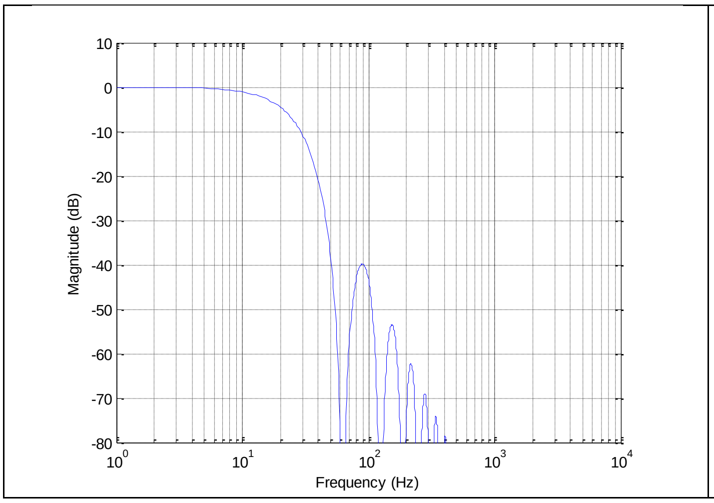

Figure 7-1: Low-pass filter characteristics with -3dB frequency at 16Hz

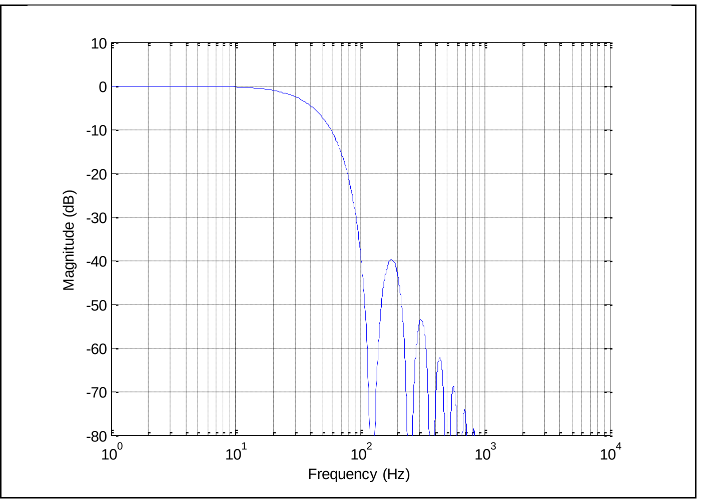

Figure 7-2: Low-pass filter characteristics with -3dB frequency at 33Hz

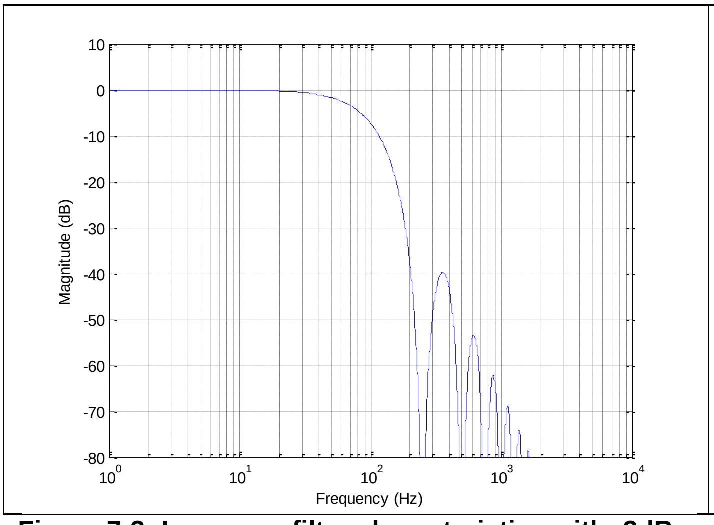

Figure 7-3: Low-pass filter characteristics with -3dB frequency at 66Hz

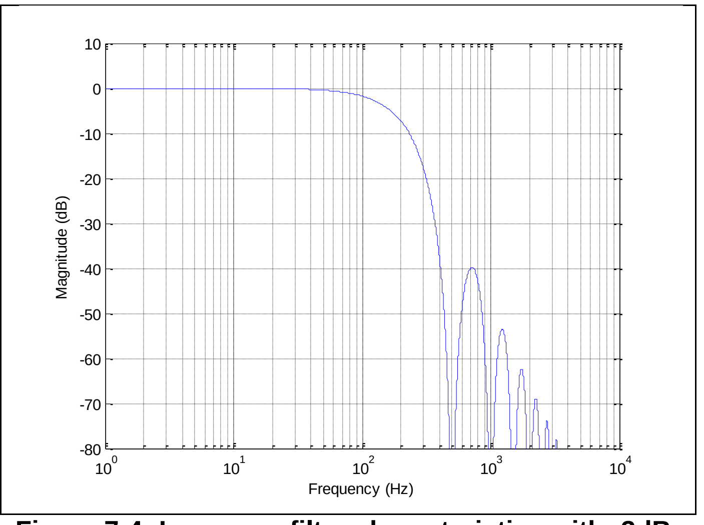

Figure 7-4: Low-pass filter characteristics with -3dB frequency at 131Hz

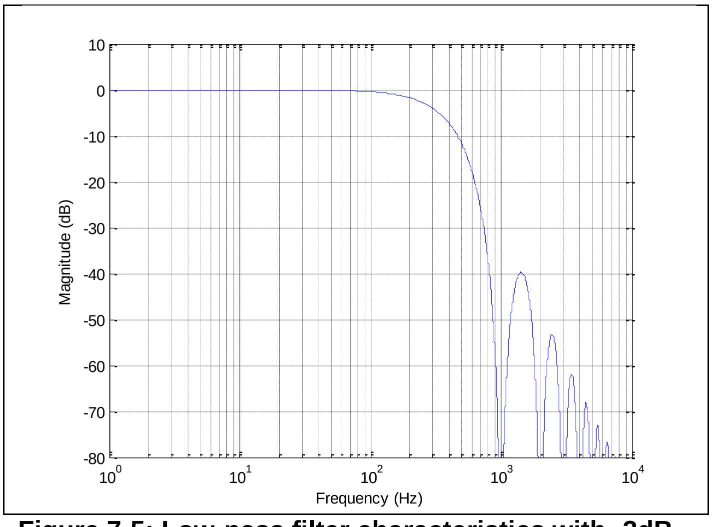

Figure 7-5: Low-pass filter characteristics with -3dB frequency at 262Hz