ELECTRONICS & DEFENSE

STIM

Application Note

Timing details between sampling and datagram transmission

SUMMARY:

This document describes in more detail the time delays between sampling, timing signals (external trigger and TOV) and the datagram transmission.

Some general equations are given in order to calculate the overall delay.

TABLE OF CONTENT:

1 SYNCHRONIZATION OF ADCs

During start-up STIM3xx will synchronize all measurement channels. The 3 gyro channels have individual ADCs, whilst the accelerometers, inclinometers and AUX-input are all handled by parallel ADCs integrated in the same chip and are by design synchronized. The synchronization during start-up ensures synchronization between the gyro ADCs and between the gyro-ADCs and the ADCs for the accelerometers, inclinometers and AUX-input. The synchronization ensures synchronized outputs from the ADCs.

2 TIME-DELAYS/GROUP DELAYS

The signal-processing chain is shown in Figure 2-1 and Figure 2-2 when output unit is set to angular rate (for gyros) or acceleration (for accelerometers or inclinometers). In this configuration the latest measurement available is transmitted in the datagram.

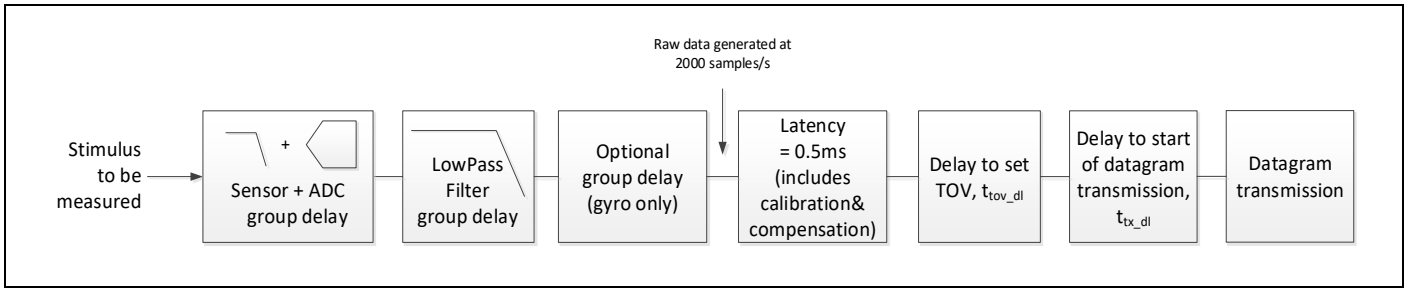

Figure 2-1: Time delays when sampling rate is not set to "External Trigger"

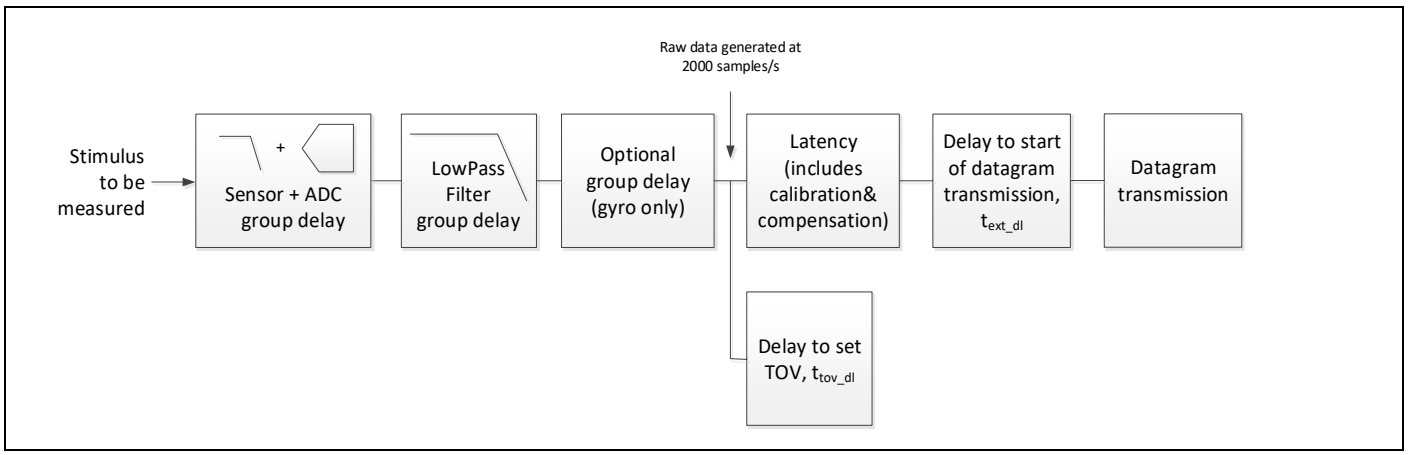

Figure 2-2: Time delays when sampling rate set to "External Trigger"

2.1 Sensor + ADC group delay

There are some differences in the group delays of sensor + ADC when comparing gyros, accelerometers, inclinometers and AUX. One significant difference is in the ADC for the accelerometers, inclinometers and AUX, which has a group delay significantly longer than for the gyros. Another significant difference is for the inclinometers, which has a group delay of approximately 9ms related to the limited bandwidth. A summary of group delays is shown in Table 2-1. Details of each sensor can be found in Appendix A.

Table 2-1: Summary of sensor + ADC group delays

Sensor	Sensor + ADC group delay STIM300/STIM377H	Sensor + ADC group delay STIM318	Sensor + ADC group delay STIM320/STIM380H
Gyro	0.71ms	0.71ms	0.71ms
Accelerometer, 5g	5.19ms	-	-
Accelerometer, 10g	5.19ms	1.51ms	1.51ms
Accelerometer, 30g	6.03ms	1.31ms	-
Accelerometer, 80g	5.22ms	1.24ms	-
Inclinometer	13.8ms	10.3ms	-
AUX	4.77ms	-	-

2.2 LowPass Filter group delay

The LowPass Filters are Cascaded Integrator-Comb (CIC) filters. They have linear phase response which means that all frequency-components will have the same group delay through the filter.

The LowPass Filter delay can be expressed as shown in Equation 2-1:

Equation 2-1: LowPass Filter delay

$$LowPassFilterDelay = 1.5ms \cdot integer\left[\frac{262Hz}{LowPassFilter} + 0.5\right] + LPFDelayOffset$$

where LowPassFilter is the chosen filter bandwidth
LPFDelayOffset (STIM300/STIM377H) = -0.05ms for gyros and -0.19ms for other sensors
LPFDelayOffset (STIM318/STIM320/STIM380H) = -0.05ms for all sensors

The LowPass Filter group delays are summarized in Table 2-2. Details of each filter can be found in Appendix B.

Table 2-2: Summary of LowPass Filter group delays

LOW-PASS FILTER -3dB FREQUENCY	LowPass Filter group delay, gyros	LowPass Filter group delay, other sensors STIM300/STIM377H	LowPass Filter group delay, other sensors STIM318/STIM320/STIM380H
16Hz	23.95ms	23.81ms	23.95ms
33Hz	11.95ms	11.81ms	11.95ms
66Hz	5.95ms	5.81ms	5.95ms
131Hz	2.95ms	2.81ms	2.95ms
262Hz	1.45ms	1.31ms	1.45ms

2.3 Optional group delay (gyro only)

Due to the significant difference in group delay between the gyro and the accelerometers (including ADC), ref. Table 2-1, the gyro measurements can be delayed by 4.5ms for STIM300 and STIM377H and 1.0ms for STIM318, STIM320 and STIM380H by choosing one of the delayed gyro output units. This may useful when the gyro- and accelerometer-measurements in a datagram should be sampled at roughly the same time and/or when utilizing the g-compensation features when utilizing the accelerometers.

2.4 Latency

Latency is the time between the availability of the raw data (filtered and optionally delayed (gyro only), but not calibrated and compensated) and the decision/request to start transmission. Data can of course not be transmitted until it has been calibrated and compensated. This takes typically 0.3 - 0.4ms. Latency can therefore never be shorter than this. If external trigger is received after the raw data is present but before the calibration and compensation has been completed, it will be the previous sample that will be transmitted and the contents of the latency will reflect the timing of this sample.

If sample rate is not set to "External Trigger", latency is always 0.5ms.

2.5 Delay to set TOV, t_{tov_dl}

Refer to the datasheets for STIM300 (TS1524), STIM377H (TS1673), STIM318 (TS1657), STIM320 (TS1665) or STIM380H (TS1696) for details on this value.

2.6 Delay to start datagram transmission, t_{tx_dl} and $text_{\_dl}$

T_{tx_dl} and t_{ext_dl} covers the time it takes to prepare the datagram for transmission. This includes calculation of CRC which also covers the latency and hence must be done after the latency value has been defined.
Refer to the datasheets for STIM300 (TS1524), STIM377H (TS1673), STIM318 (TS1657), STIM320 (TS1665) or STIM380H (TS1696) for details on t_{tx_dl} and t_{ext_dl}.

2.7 Datagram transmission delay

The datagram transmission delay is dependent on the following parameters:

- Length of datagram
- Choice of parity bit and number of stop-bits
- Bit-rate

3 TOTAL GROUP DELAYS

Total group delay is in this context defined as the combination of sensor + ADC group delay and LowPass Filter group delay. A summary of total group delays is shown in Table 3-1 and Table 3-2 for STIM300 and STIM377H and STIM318, STIM320 and STIM380H respectively. Details of each sensor can be found in the preceding sub-chapters.

Table 3-1: Summary of total group delays STIM300/STIM377H

Sensor	Total group delay				
	LowPass Filter = 16Hz	LowPass Filter = 33Hz	LowPass Filter = 66Hz	LowPass Filter = 131Hz	LowPass Filter = 262Hz
Gyro	24.67ms	12.67ms	6.67ms	3.67ms	2.17ms
Accelerometer, 5+10g	29.00ms	17.00ms	11.00ms	8.00ms	6.50ms
Accelerometer, 30g	29.84ms	17.84ms	11.84ms	8.84ms	7.34ms
Accelerometer, 80g	29.03ms	17.03ms	11.03ms	8.03ms	6.53ms
Inclinometer	37.75ms	25.75ms	19.75ms	16.75ms	15.25ms
AUX	28.58ms	16.58ms	10.58ms	7.58ms	6.08ms

Table 3-2: Summary of total group delays STIM318/STIM320/STIM380H

Sensor	Total group delay				
	LowPass Filter = 16Hz	LowPass Filter = 33Hz	LowPass Filter = 66Hz	LowPass Filter = 131Hz	LowPass Filter = 262Hz
Gyro	24.67ms	12.67ms	6.67ms	3.67ms	2.17ms
Accelerometer, 5g	25.58ms	13.58ms	7.58ms	4.58ms	3.08ms
Accelerometer, 10g	25.46ms	13.46ms	7.46ms	4.46ms	2.96ms
Accelerometer, 30g	25.26ms	13.26ms	7.26ms	4.26ms	2.76ms
Accelerometer, 80g	25.19ms	13.19ms	7.19ms	4.19ms	2.69ms
Inclinometer (STIM318)	34.32ms	22.32ms	16.32ms	13.32ms	11.82ms

4 MODELS OF TOTAL DELAY

Based on Figure 2-1 a model can be established for the total delay from sample to the time at which TOV goes active or to the time the datagram transmission starts when sample rate is not set to "External Trigger", see Equation 4-1. As there may be several samples represented in the datagram (e.g. when using incremental or average), Equation 4-1 calculates the average delay. The equation is also valid when number of samples is 1.

Equation 4-1: Model of total delay when sample rate is not set to "External Trigger"

$$TotalDelay = Sensor\&ADC\_Delay + 1.5ms \cdot integer\left[\frac{262Hz}{LowPassFilter} + 0.5\right] + LPF\_DelayOffset + OptionalDelay + \frac{0.5ms \cdot \sum_{n=1}^{\#samples} n}{\#samples} + t_{tov_{dl}} + t_{tx_{dl}} + \frac{\#datagram\_bytes \cdot (1 + 8 + \#parity\_bit + \#stop\_bits)}{bit\_rate}$$

Where

- Sensor&ADC:Delay: ref. Table 2-1 and APPENDIX A
- LowPassFilter is the selected bandwidth
- LPF_DelayOffset for STIM300 is -0.05ms for gyros and -0.19ms for other sensors
- LPF_DelayOffset for STIM318 is -0.05ms
- OptionalDelay (valid for gyros only): 4.5ms for STIM300/STIM377H, 1.0ms for STIM318/STIM320/STIM380H
- t_{tov_dl}: ref. section 2.5 and product datasheet
- t_{tx_dl}: ref. section 2.6 and product datasheet
- #samples is the number of samples on which the data in the datagram is based on, ref. Table 4-1
- #datagram_bytes is the number of transmitted bytes in each datagram, ref. product datasheet
- #parity_bit is the number of parity bits (None = 0, bits, Even or Odd = 1 bit)
- #stop_bits is the number of stop bits (1 or 2 bits)
- bit_rate is the chosen RS422 bit-rate

Table 4-1: #samples for different output units

Output Unit				
Gyros	**Accelerometers**	**Inclinometers**	**AUX**	**#samples**
Angular rate Angular rate - delayed	Acceleration	Acceleration	Voltage	1
Incremental angle Average angular rate Incremental angle – delayed Average angular rate - delayed	Incremental velocity Average acceleration	Incremental velocity Average acceleration	Not Applicable	$\frac{2000}{SampleRate}$

Similarly, a model can be established based on Figure 2-2 for "External Trigger" in order to calculate the total delay from sample to the time of the external trigger or to the time when the datagram transmission starts, ref. Equation 4-2:

Equation 4-2: Model of total delay when sample rate is set to "External Trigger"

$$TotalDelayExtTrig = Sensor\&ADC\_Delay + 1.5ms \cdot integer\left[\frac{262Hz}{LowPassFilter} + 0.5\right] + LPF\_DelayOffset + OptionalDelay + \frac{Latency + 0.5ms \cdot \sum_{n=2}^{\#samples} n}{\#samples} + t_{ext_{dl}} + \frac{\#datagram\_bytes \cdot (1 + 8 + \#parity\_bit + \#stop\_bits)}{bit\_rate}$$

Where

- Sensor&ADC_Delay: ref. Table 2-1 and APPENDIX A
- LowPassFilter is the selected bandwidth
- LPF_DelayOffset, STIM300, is -0.05ms for gyros and -0.19ms for other sensors
- LPF_DelayOffset, STIM318, is -0.05ms
- OptionalDelay (valid for gyros only): 4.5ms for STIM300/STIM377H, 1.0ms for STIM318/STIM320/STIM380H
- Latency: latency value in datagram, ref. section 2.4 and product datasheet
- t_{tov_dl}: ref. section 2.5 and product datasheet
- t_{ext_dl}: ref. section 2.6 and product datasheet
- #samples is the number of samples on which the data in the datagram is based on, ref. Table 4-2
- #datagram_bytes is the number of transmitted bytes in each datagram, ref. product datasheet
- #parity_bit is the number of parity bits (None = 0, bits, Even or Odd = 1 bit)
- #stop_bits is the number of stop bits (1 or 2 bits)
- bit_rate is the chosen RS422 bit-rate

Table 4-2: #samples for the different output units

Output Unit				
Gyros	**Accelerometers**	**Inclinometers**	**AUX**	**#samples**
Angular rate Angular rate - delayed	Acceleration	Acceleration	Voltage	1
Incremental angle Average angular rate Incremental angle – delayed Average angular rate - delayed	Incremental velocity Average acceleration	Incremental velocity Average acceleration	Not Applicable	If $counter_n > counter_{n-1}$: $\#samples = counter_n - counter_{n-1}$ If $counter_n < counter_{n-1}$: $\#samples = 256 + counter_n - counter_{n-1}$ where • $counter_n$ is the counter-value of the current datagram • $counter_{n-1}$ is the counter-value of the previous datagram

4.1 Example#1 – no external trigger

Product: STIM300, 400°/s, 5g
Datasheet: TS1524 rev.27
Output Unit:
- Gyro: Angular rate - delayed
- Accelerometer: Acceleration
- Inclinometer: Incremental velocity
- AUX: Voltage

LP Filter:
- Gyro: 66Hz
- Accelerometer: 66Hz
- Inclinometer: 33Hz
- AUX: 16Hz

Sample rate: 500 samples/s
Datagram: Rate, acceleration, inclination and AUX = 42 bytes
RS422 configuration: no parity, 1 stop-bit = 10bits/character, bit-rate = 460800 bits/s

Table 4-3: Calculation of total delay, no external trigger

Parameter	Gyro	Accelerometer	Inclinometer	AUX
$Sensor\&ADC\_Delay$	0.71ms	5.19ms	13.8ms	4.77ms
$1.5ms \cdot integer\left[\frac{262Hz}{LowPassFilter} + 0.5\right]$	6.00ms	6.00ms	12.00ms	24.00ms
$LPF\_DelayOffset$	-0.05ms	-0.19ms	-0.19ms	-0.19ms
$OptionalDelay$	4.50ms	-	-	-
$\frac{0.5ms \cdot \sum_{n=1}^{\#samples} n}{\#samples}$	0.50ms	0.50ms	1.25ms*	0.50ms
$t_{tov_{dl}}$	0.0012ms	0.0012ms	0.0012ms	0.0012ms
$t_{tx_{dl}}$	0.08ms (max)	0.080ms (max)	0.080ms (max)	0.080ms (max)
$\frac{\#datagram\_bytes \cdot (1 + 8 + \#parity\_bit + \#stop\_bits)}{bit\_rate}$	0.91ms	0.91ms	0.91ms	0.91ms
Total	**12.65ms**	**12.49ms**	**27.85ms**	**30.07ms**

*) #samples = 2000/500 = 4, $\sum_{n=1}^{\#samples} n$ = 1+2+3+4 = 10

4.2 Example#2 – external trigger

Product: STIM318, 400°/s, 10g
Datasheet: TS1657 rev.8
Output Unit:
- Gyro: Angular rate
- Accelerometer: Average acceleration

LP Filter:
- Gyro: 131Hz
- Accelerometer: 131Hz

Sample rate: External trigger
- Latency = 0.38ms
- #samples = $\text{counter}_{\text{current\_sample}} - \text{counter}_{\text{previous samples}} = 14$

Datagram: Rate and acceleration = 28 bytes
RS422 configuration: odd parity, 2 stop-bits = 12bits/character, bit-rate = 921600 bits/s

Table 4-4: Calculation of total delay, external trigger

Parameter	Gyro	Accelerometer
$Sensor\&ADC\_Delay$	0.71ms	1.51ms
$1.5ms \cdot integer\left[\frac{262Hz}{LowPassFilter} + 0.5\right]$	3.00ms	3.00ms
$LPF\_DelayOffset$	-0.05ms	-0.05ms
$OptionalDelay$	0.00ms	-
$\frac{Latency + 0.5ms \cdot \sum_{n=2}^{\#samples} n}{\#samples}$	0.38ms	3.74ms*
$t_{ext_{dl}}$	0.086ms (max)	0.086ms (max)
$\frac{\#datagram\_bytes \cdot (1 + 8 + \#parity\_bit + \#stop\_bits)}{bit\_rate}$	0.36ms	0.36ms
Total	**4.49ms**	**8.65ms**

*) #samples = 14, $\sum_{n=2}^{\#samples} n$ = 2+3+4+5+6+7+8+9+10+11+12+13+14 = 104

APPENDIX A: Plots of sensor + ADC group delays

Gyro + ADC group delay

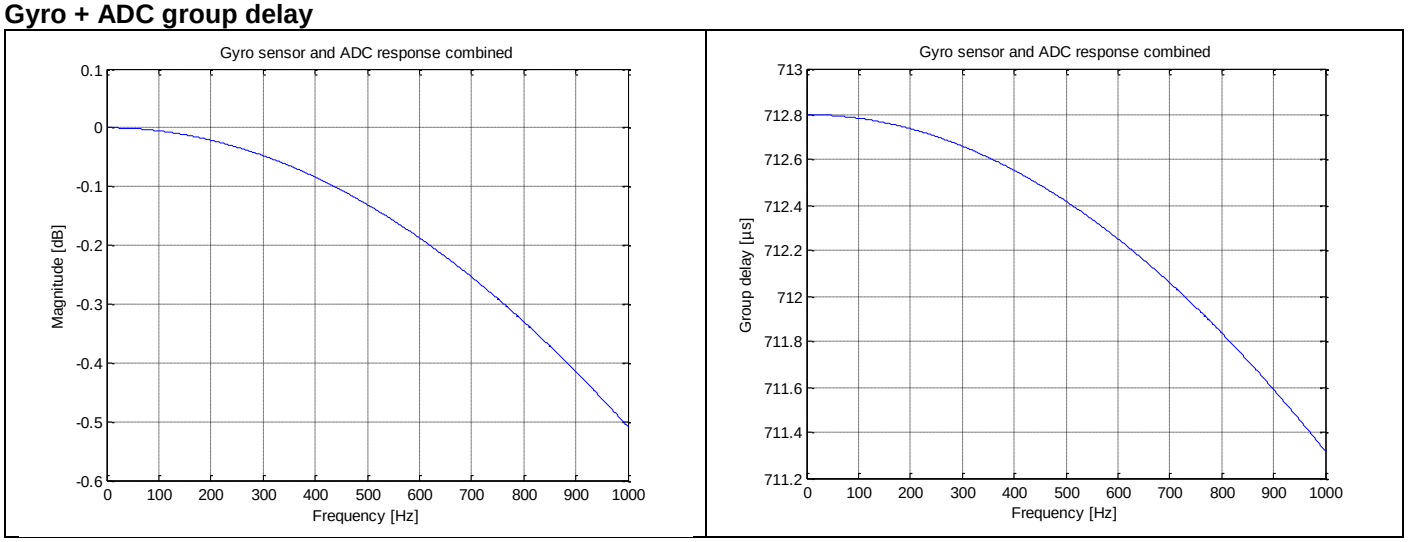

Figure A-1: Gyro + ADC amplitude response (left) and group delay (right)

STIM300/STIM377H Accelerometer (5g+10g) + ADC group delay

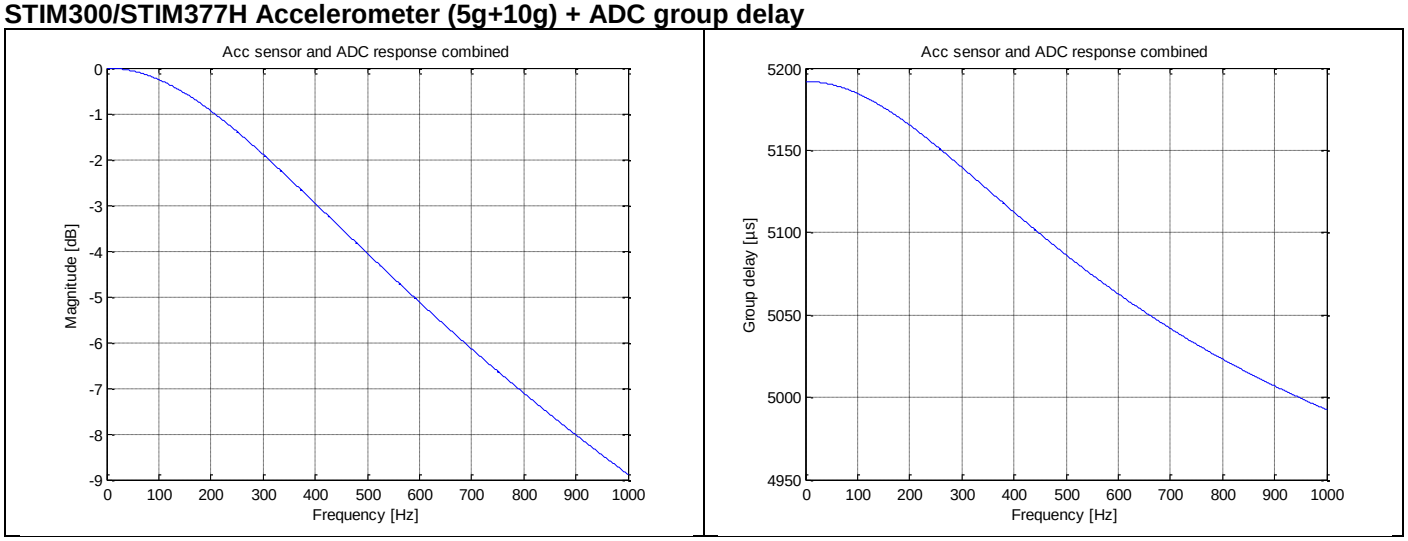

Figure A-2: STIM300/STIM377H Accelerometer (5g + 10g) + ADC amplitude response (left) and group delay (right)

STIM300/STIM377H Accelerometer (30g) + ADC group delay

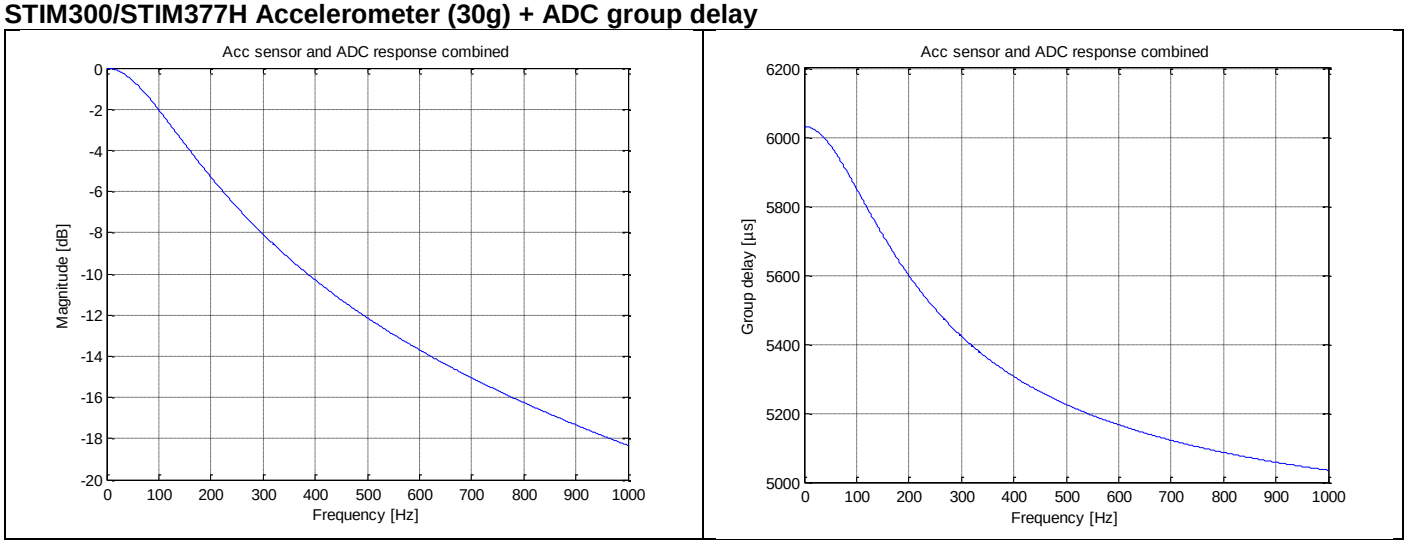

Figure A-3: STIM300/STIM377H Accelerometer (30g) + ADC amplitude response (left) and group delay (right)

STIM300/STIM377H Accelerometer (80g) + ADC group delay

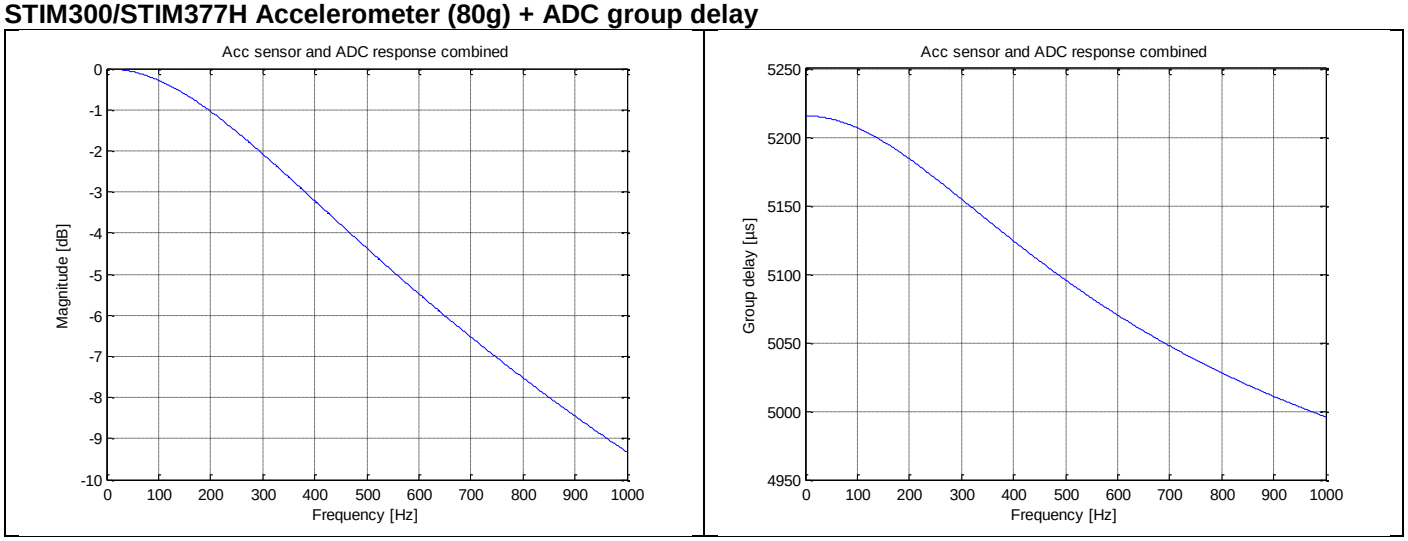

Figure A-4: STIM300/STIM377H Accelerometer (80g) + ADC amplitude response (left) and group delay (right)

STIM300/STIM377H Inclinometer + ADC group delay

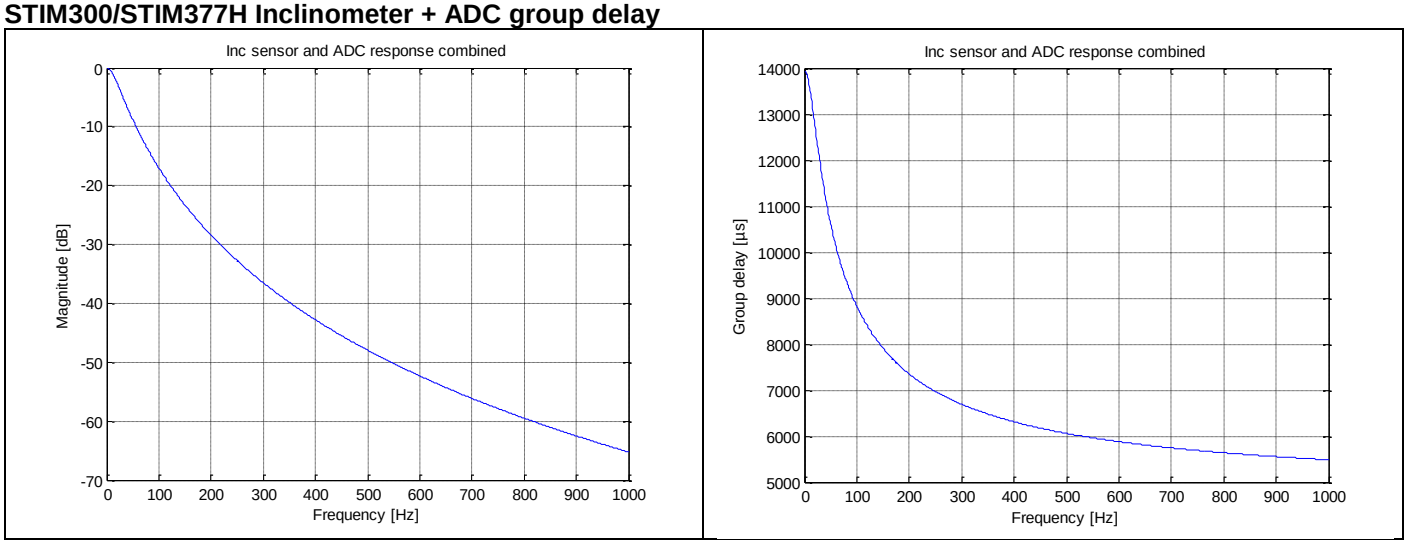

Figure A-5: STIM300/STIM377H Inclinometer + ADC amplitude response (left) and group delay (right)

STIM300/STIM377H AUX + ADC group delay

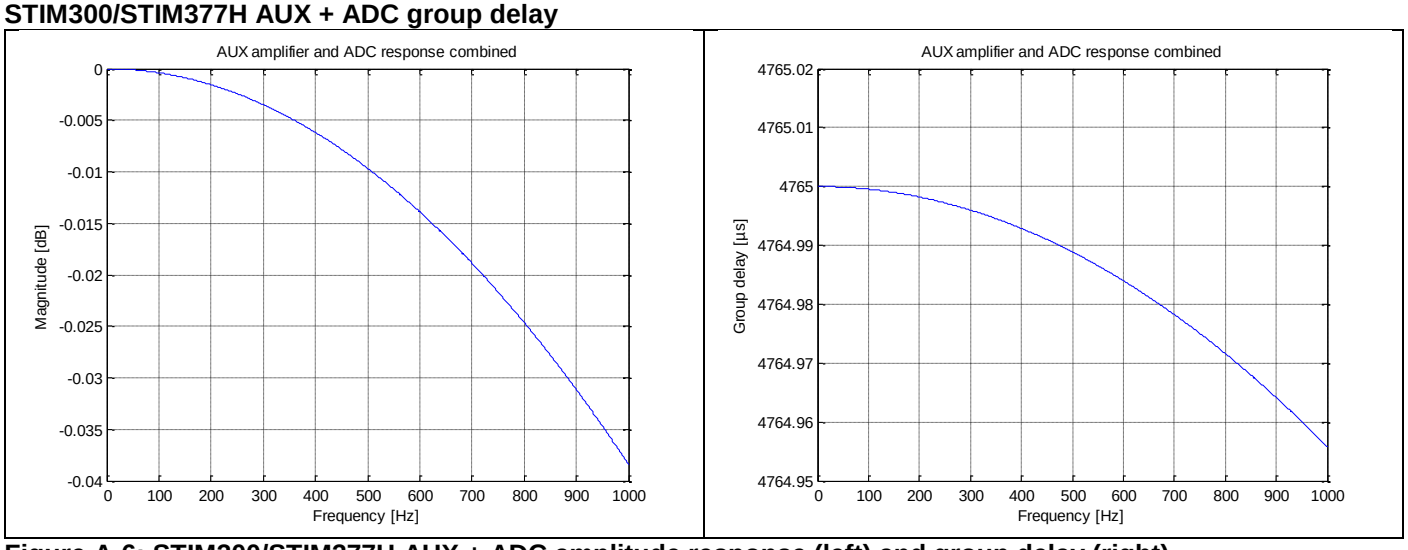

Figure A-6: STIM300/STIM377H AUX + ADC amplitude response (left) and group delay (right)

STIM318 Accelerometer (10g) + ADC group delay

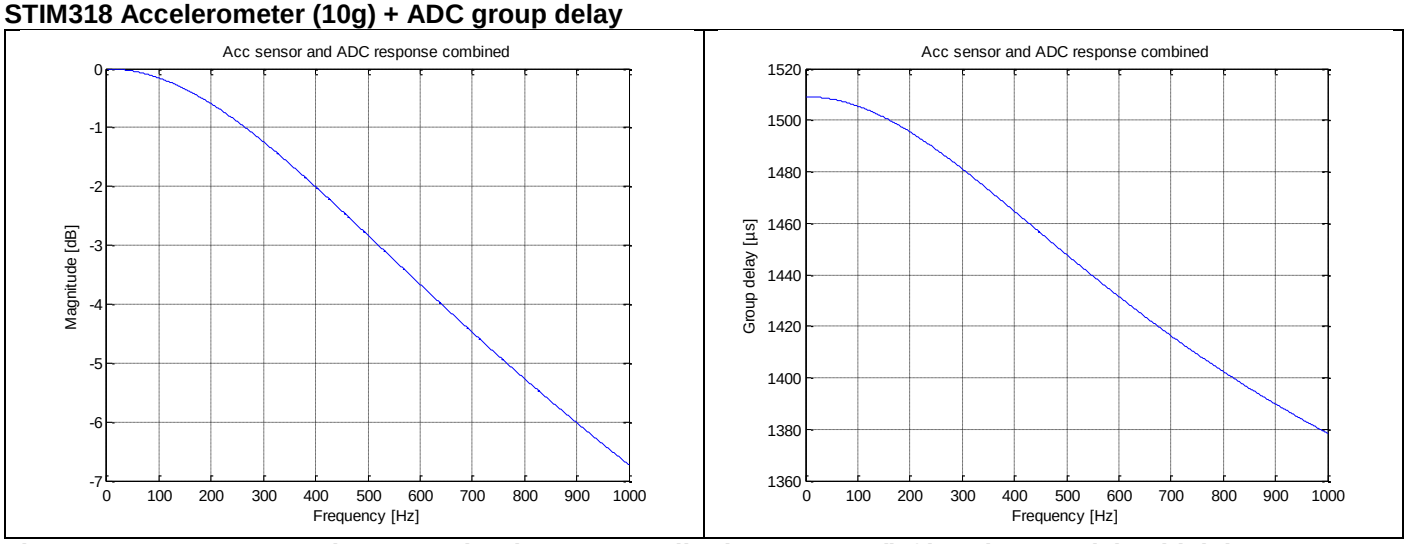

Figure A-7: STIM318 Accelerometer (10g) + ADC amplitude response (left) and group delay (right)

STIM318 Accelerometer (30g) + ADC group delay

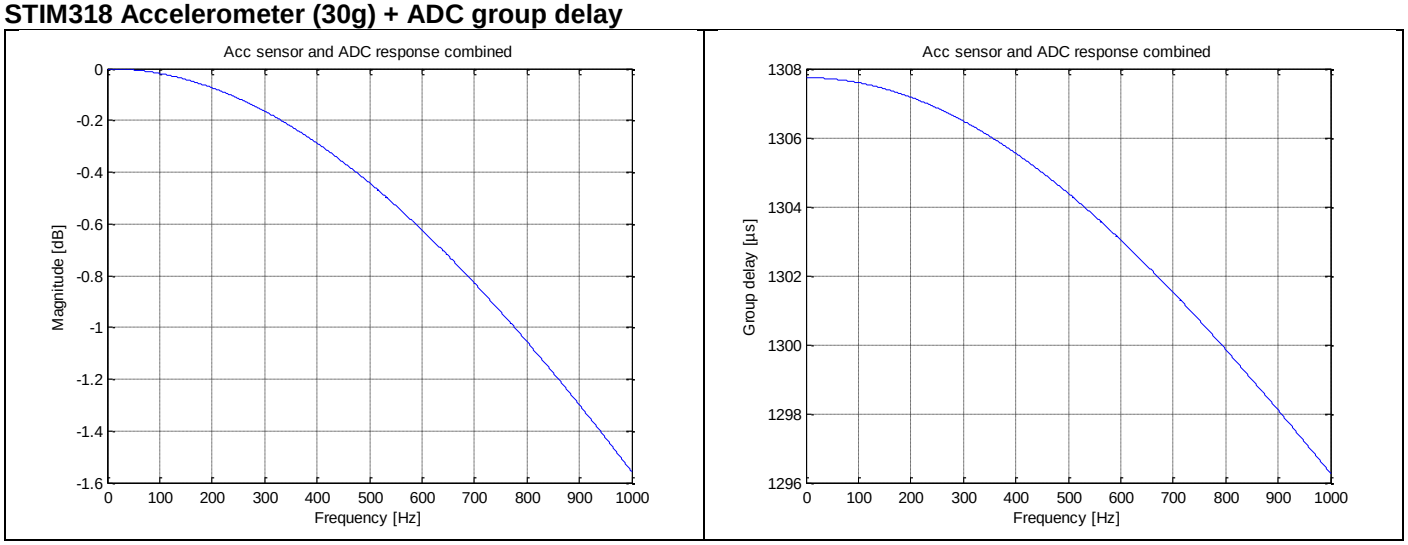

Figure A-8: STIM318 Accelerometer (30g) + ADC amplitude response (left) and group delay (right)

STIM318 Accelerometer (80g) + ADC group delay

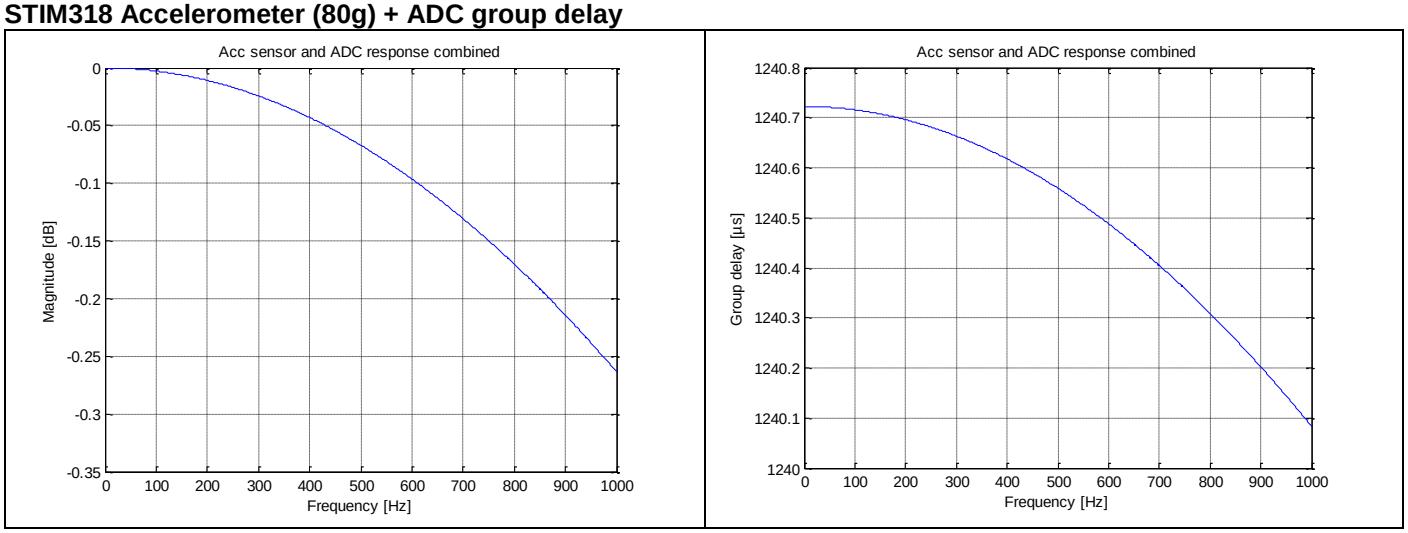

Figure A-9: STIM318 Accelerometer (80g) + ADC amplitude response (left) and group delay (right)

STIM318 Inclinometer + ADC group delay

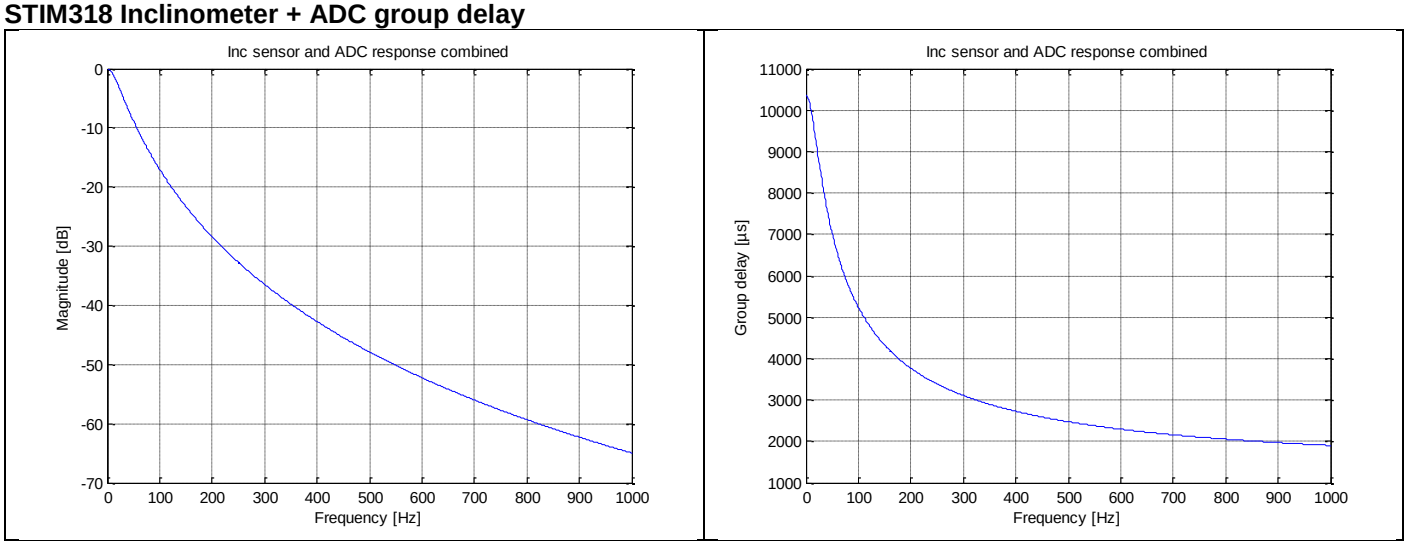

Figure A-10: STIM318 Inclinometer + ADC amplitude response (left) and group delay (right)

APPENDIX B: Plots of LowPassFilter group delays

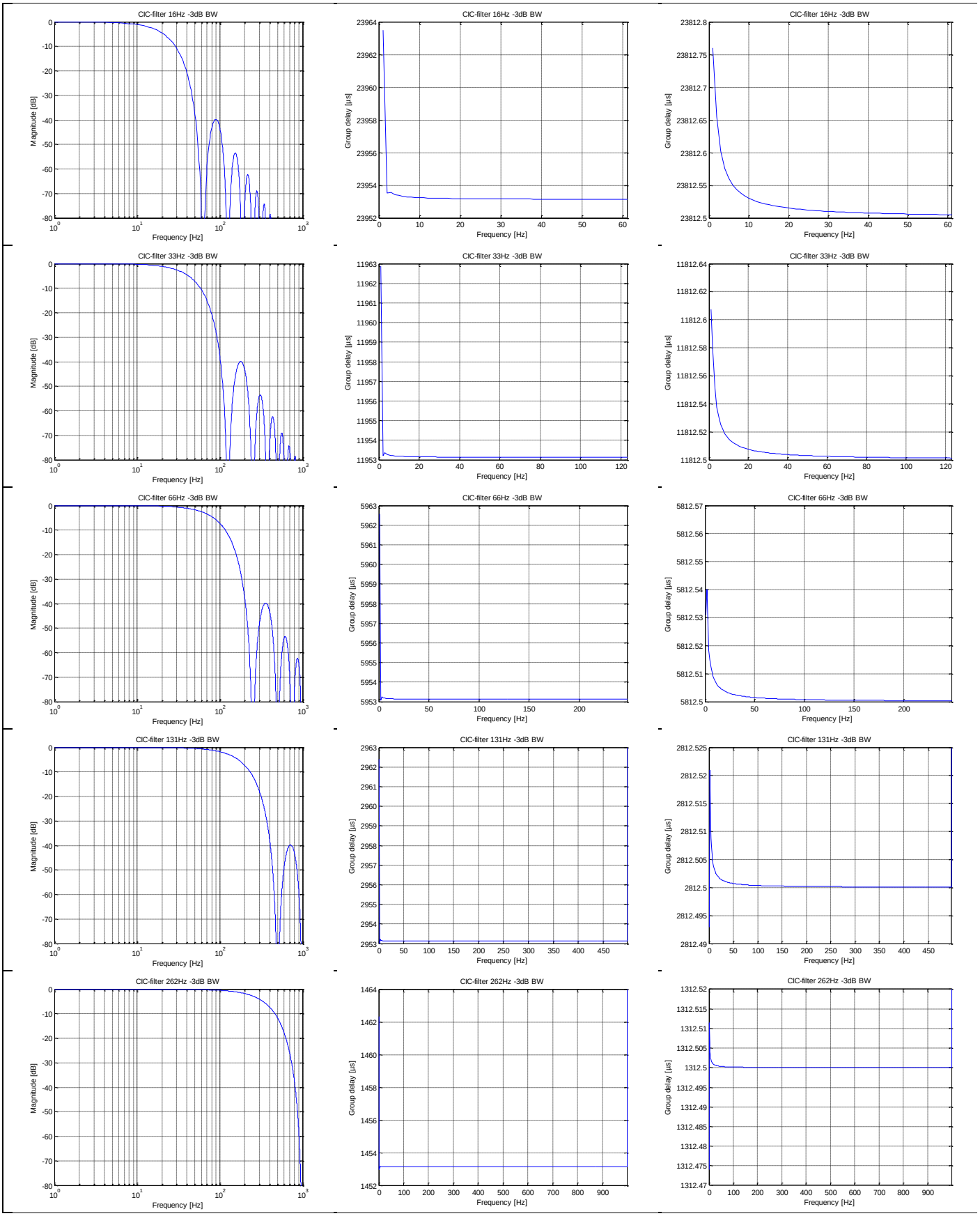

Figure B-1: STIM300/STIM377H: LowPass Filter amplitude response (left), group delay - gyros (middle) and group delay – others (right)

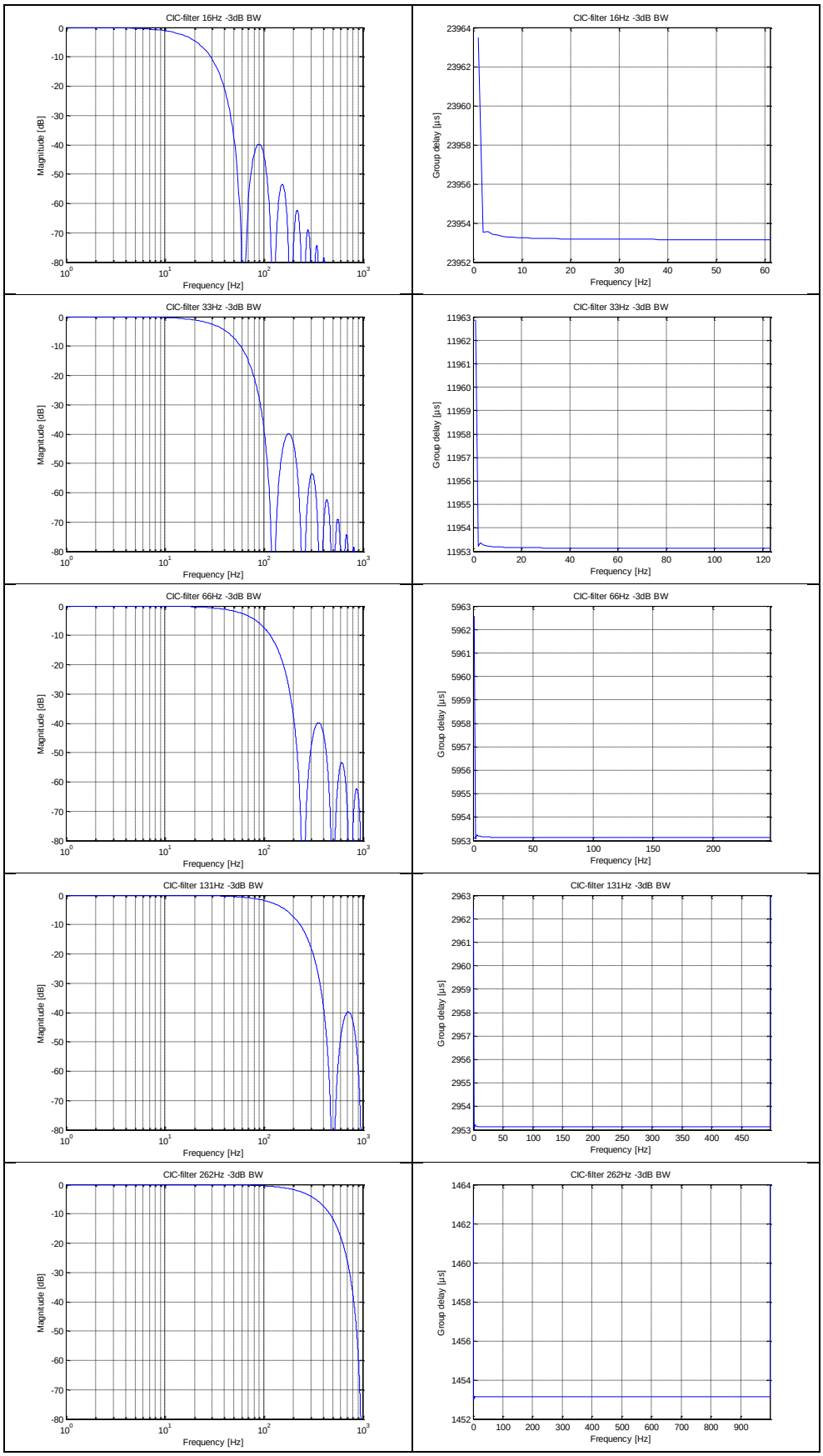

Figure B-2: STIM318/STIM320/STIM380H: LowPass Filter amplitude response (left), group delay (right)

APPENDIX C: Plots of total sensor group delays

Gyro total group delay (with the optional delay not activated)

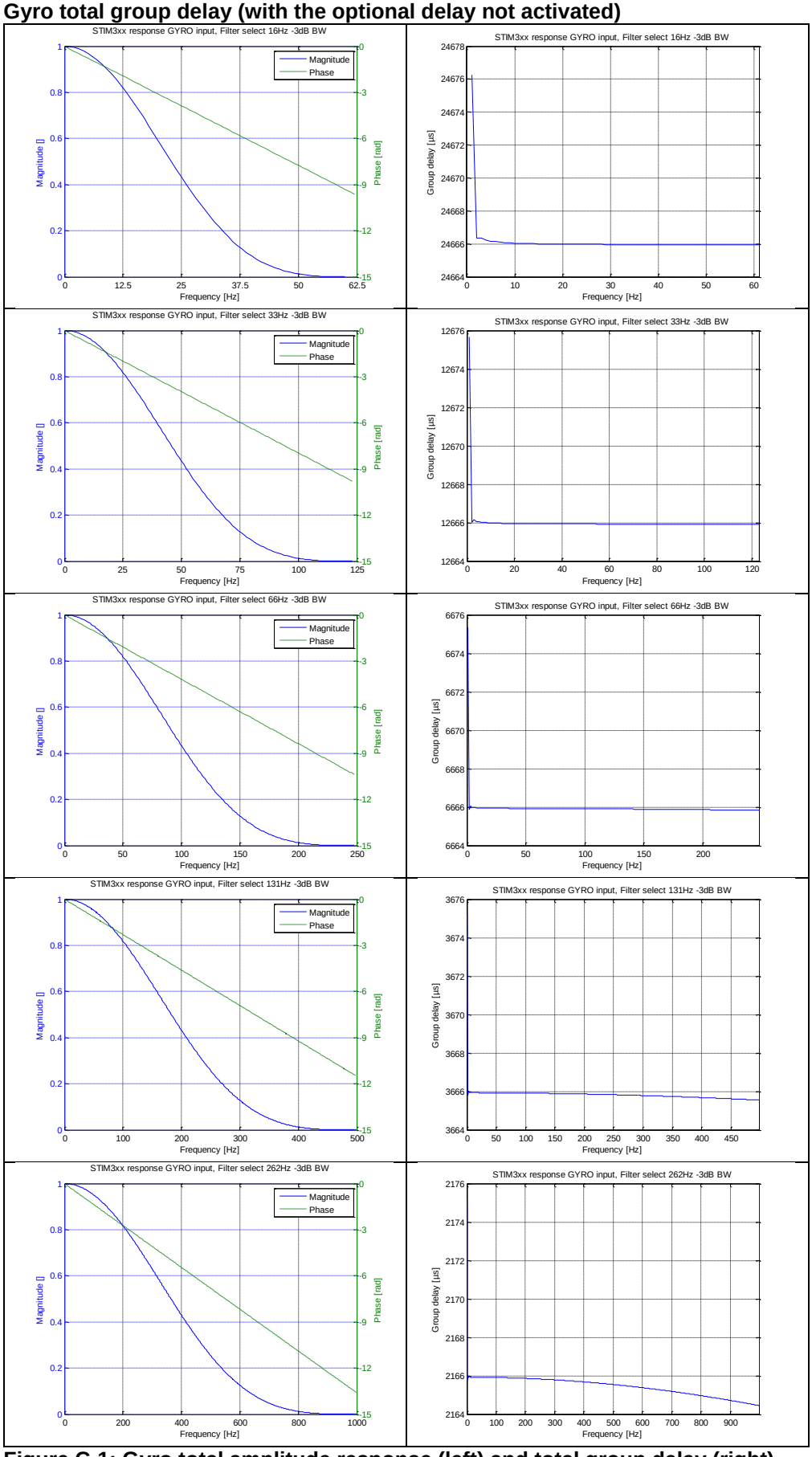

Figure C-1: Gyro total amplitude response (left) and total group delay (right)

STIM300/STIM377H Accelerometer (5g+10g) total group delay

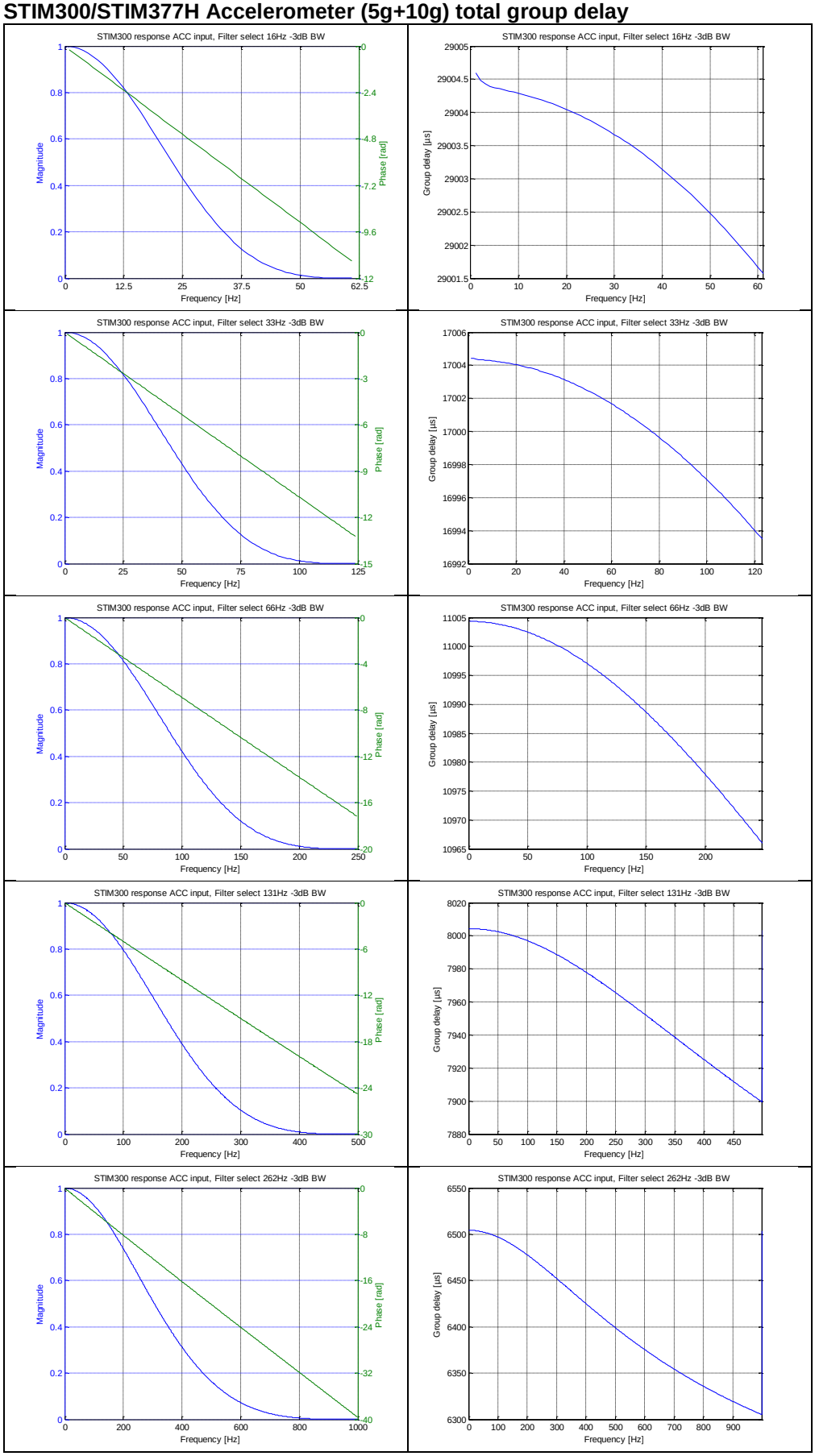

Figure C-2: STIM300/STIM377H Accelerometer (5g+10g) total amplitude response (left) and total group delay (right)

STIM300/STIM377H Accelerometer (30g) total group delay

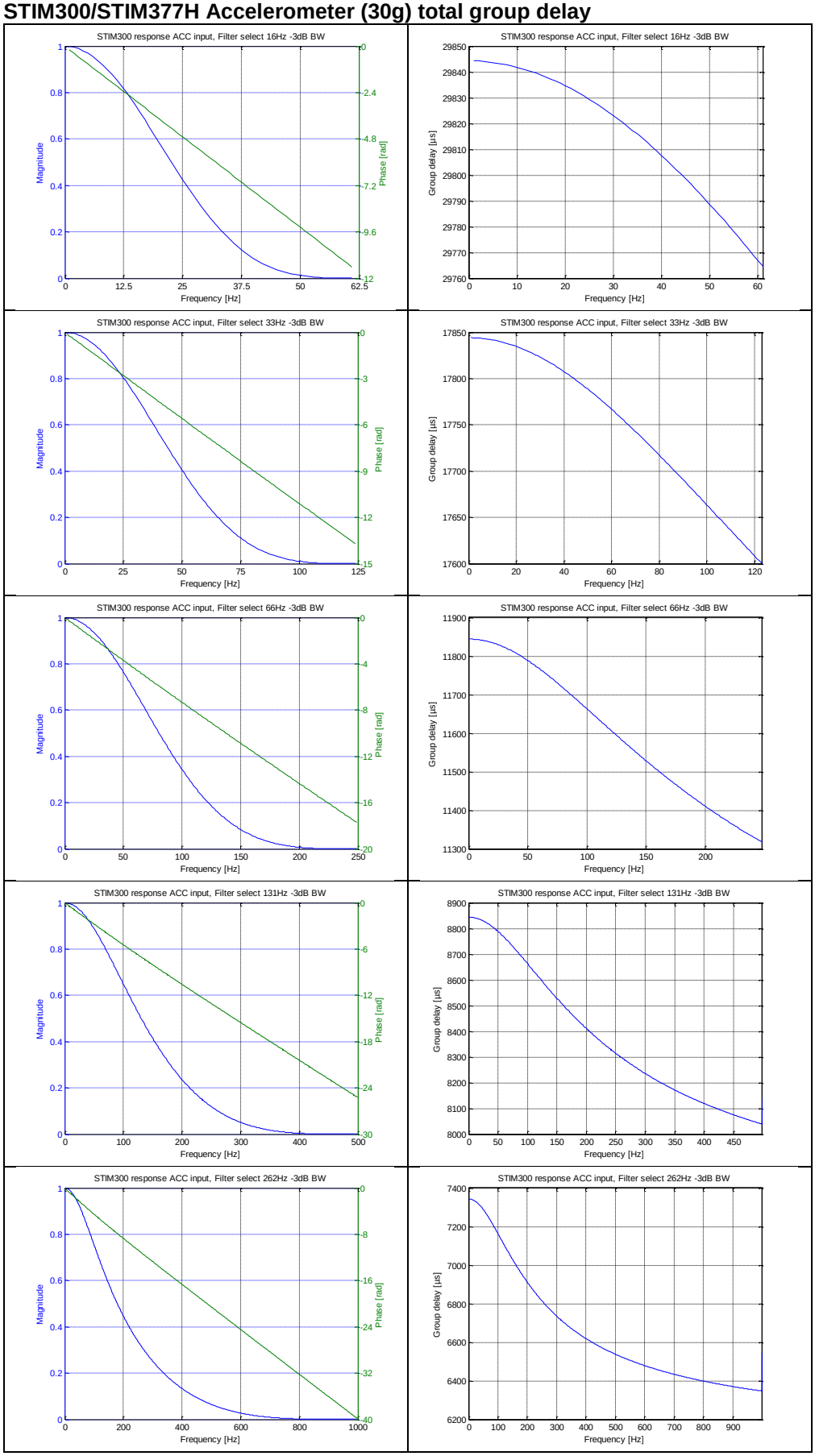

Figure C-3: STIM300/STIM377H Accelerometer (30g) total amplitude response (left) and total group delay (right)

STIM300/STIM377H Accelerometer (80g) total group delay

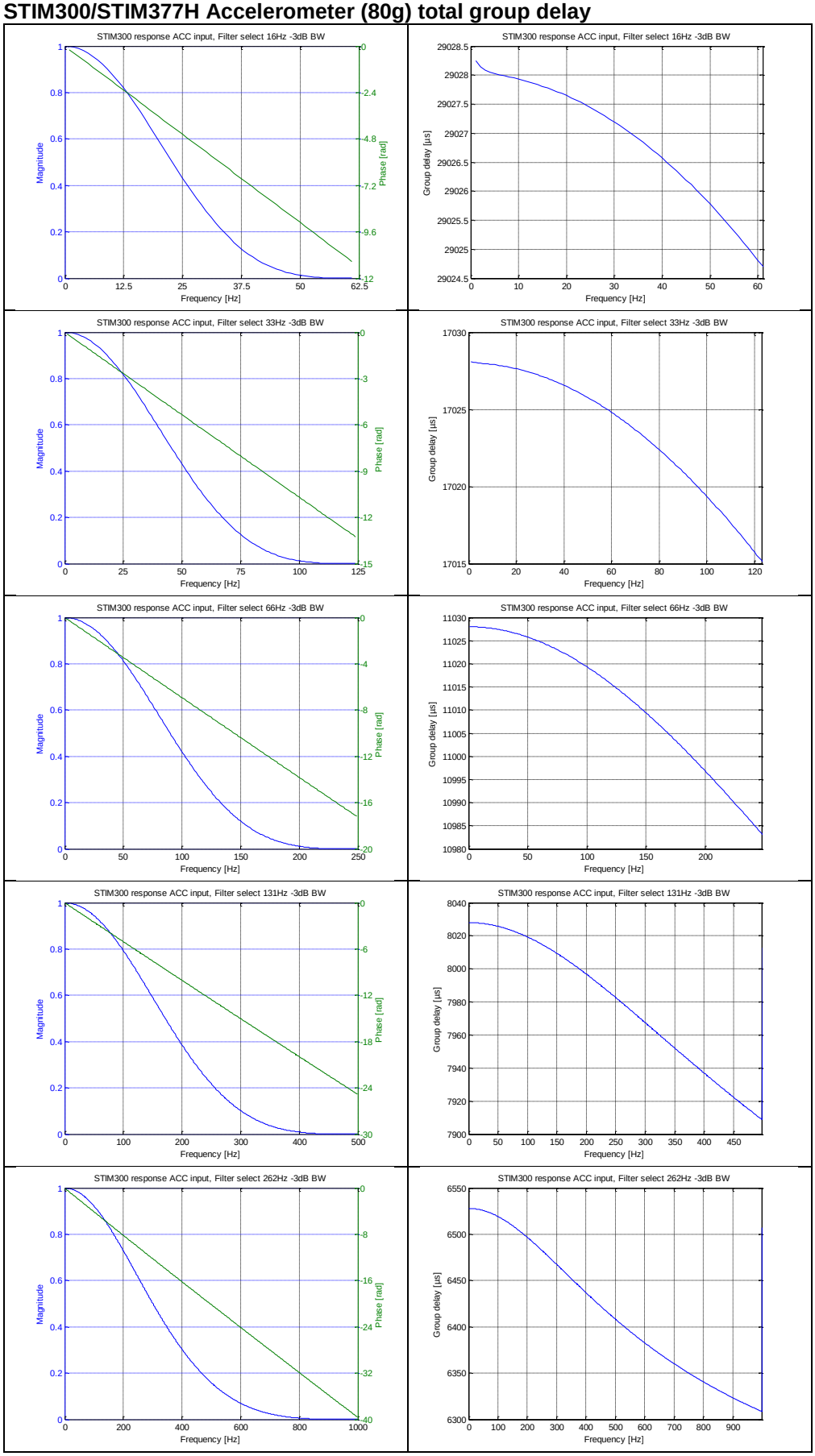

Figure C-4: STIM300/STIM377H Accelerometer (80g) total amplitude response (left) and total group delay (right)

STIM300/STIM377H Inclinometer total group delay

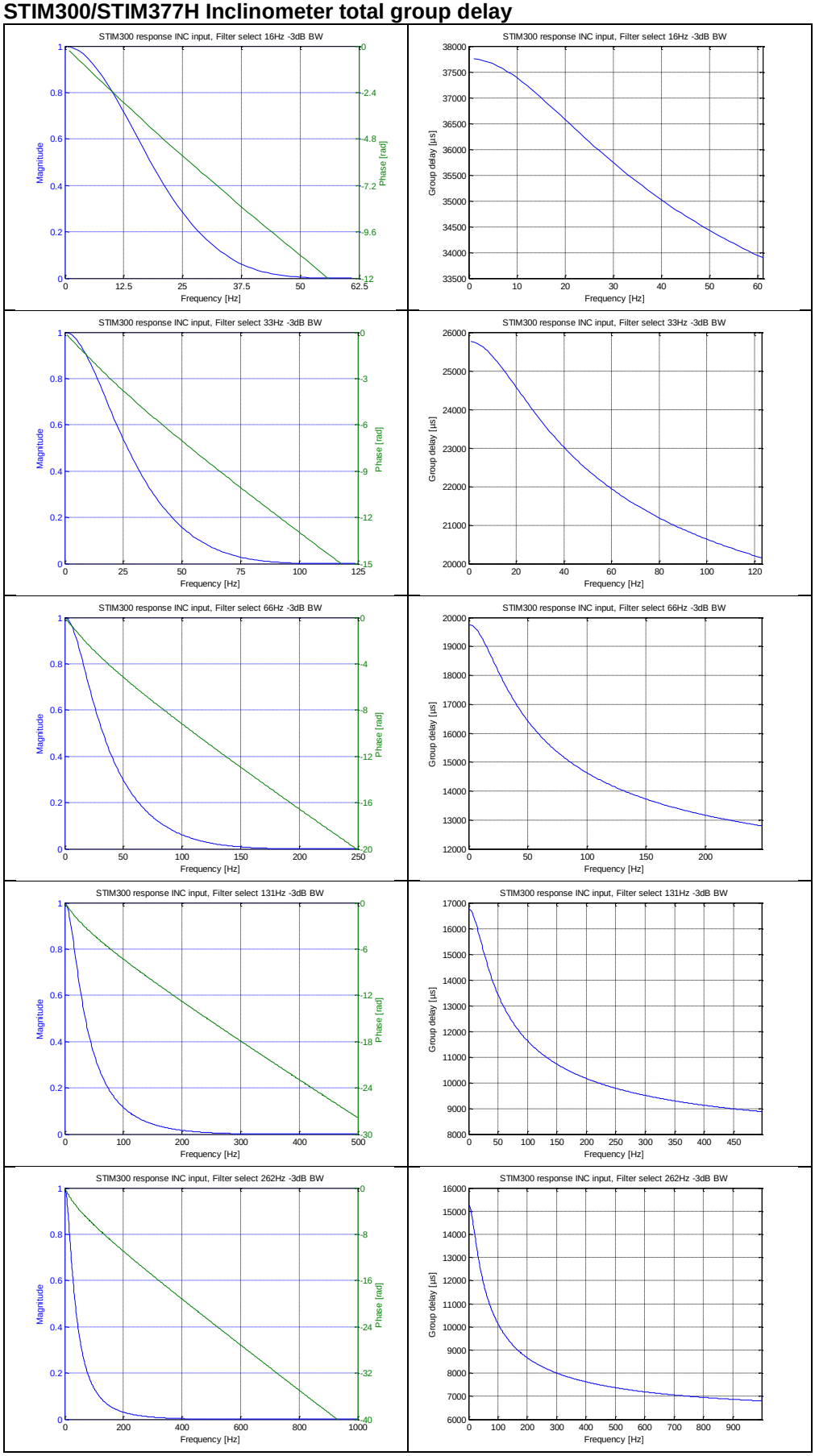

Figure C-5: STIM300/STIM377H Inclinometer total amplitude response (left) and total group delay (right)

STIM300/STIM377H AUX total group delay

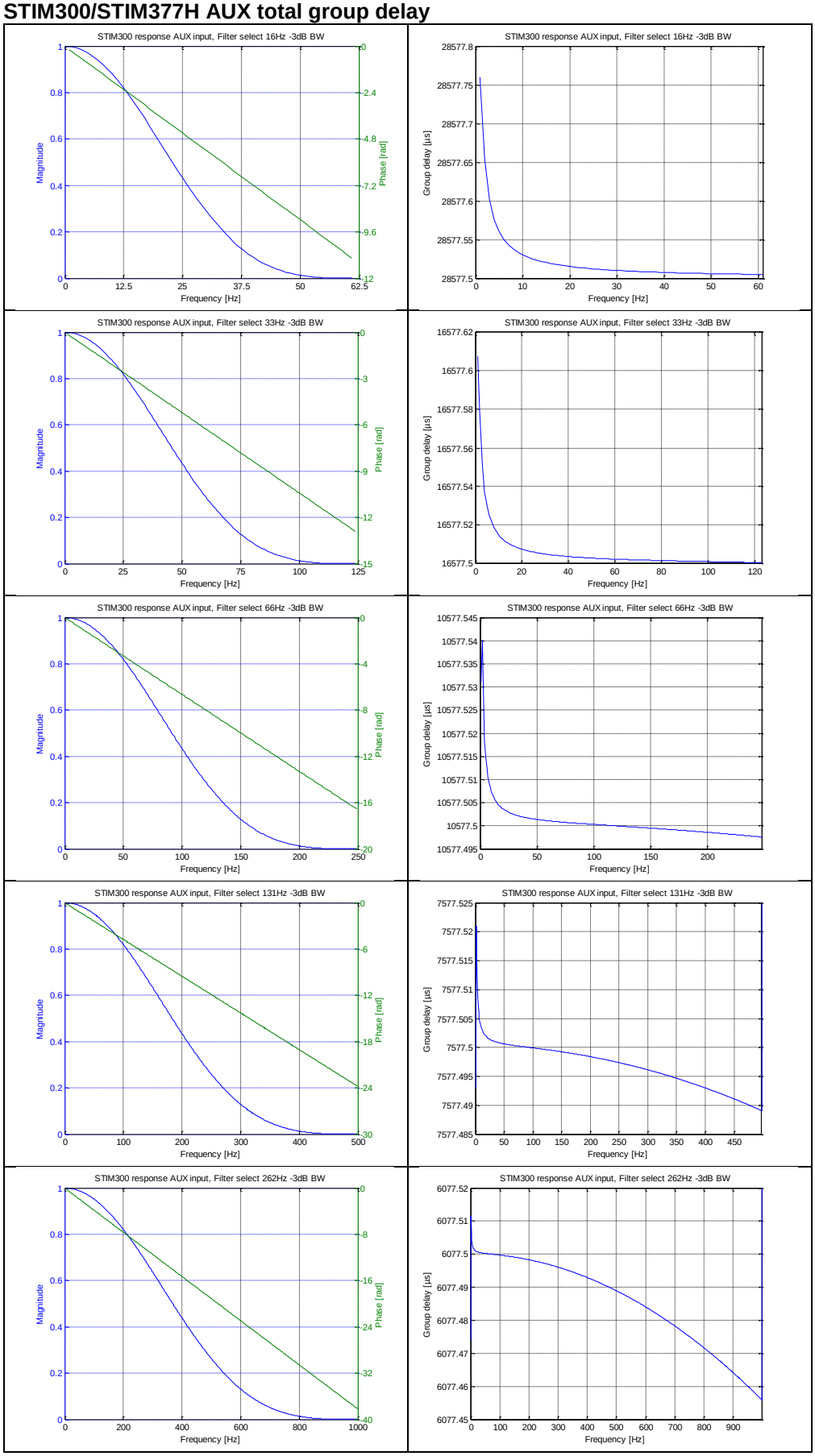

Figure C-6: STIM300/STIM377H AUX total amplitude response (left) and total group delay (right)

STIM318/STIM320/STIM380H Accelerometer (10g) total group delay

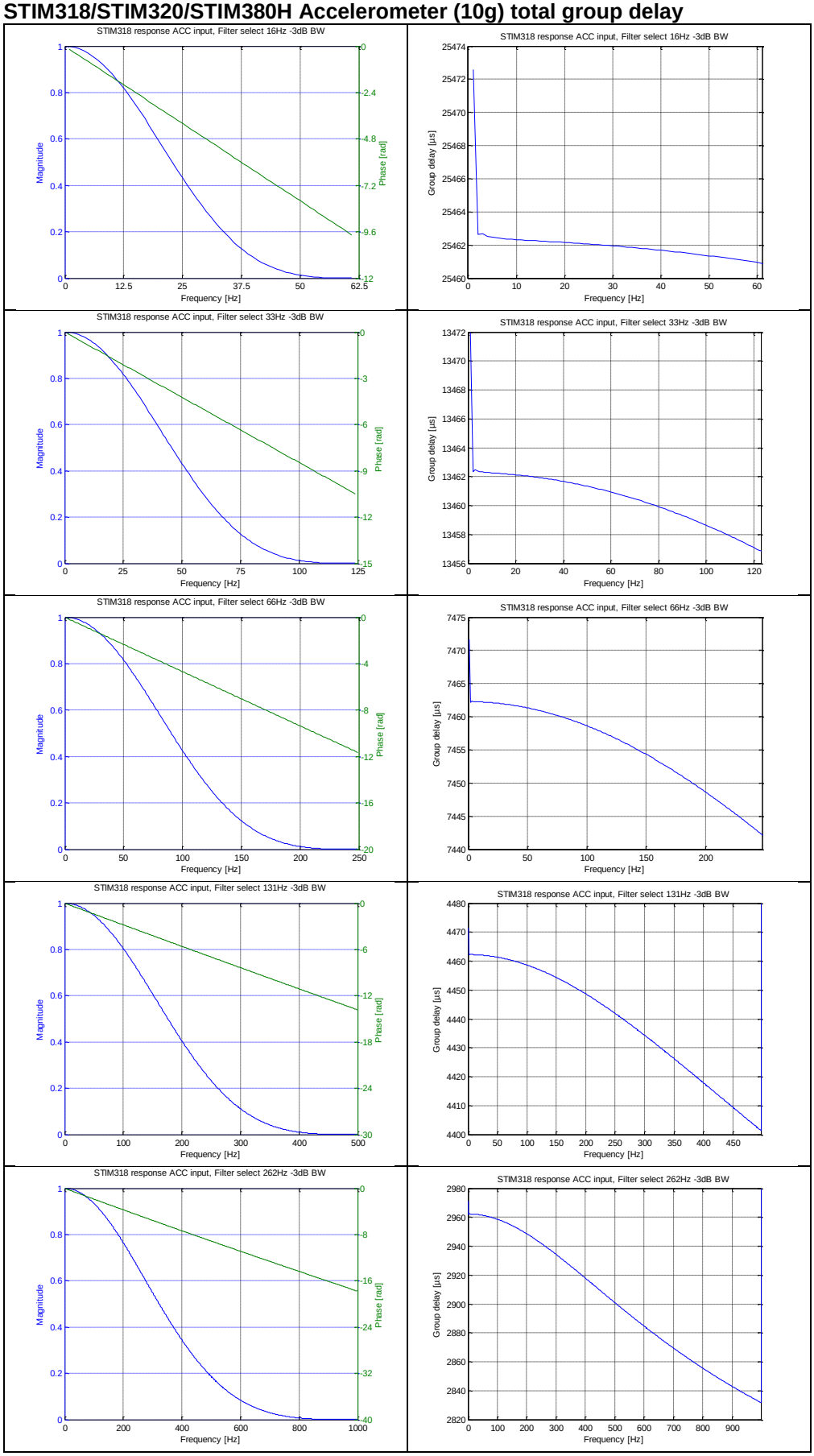

Figure C-7: STIM318/STIM320/STIM380H Accelerometer (10g) total amplitude response (left) and total group delay (right)

STIM318 Accelerometer (30g) total group delay

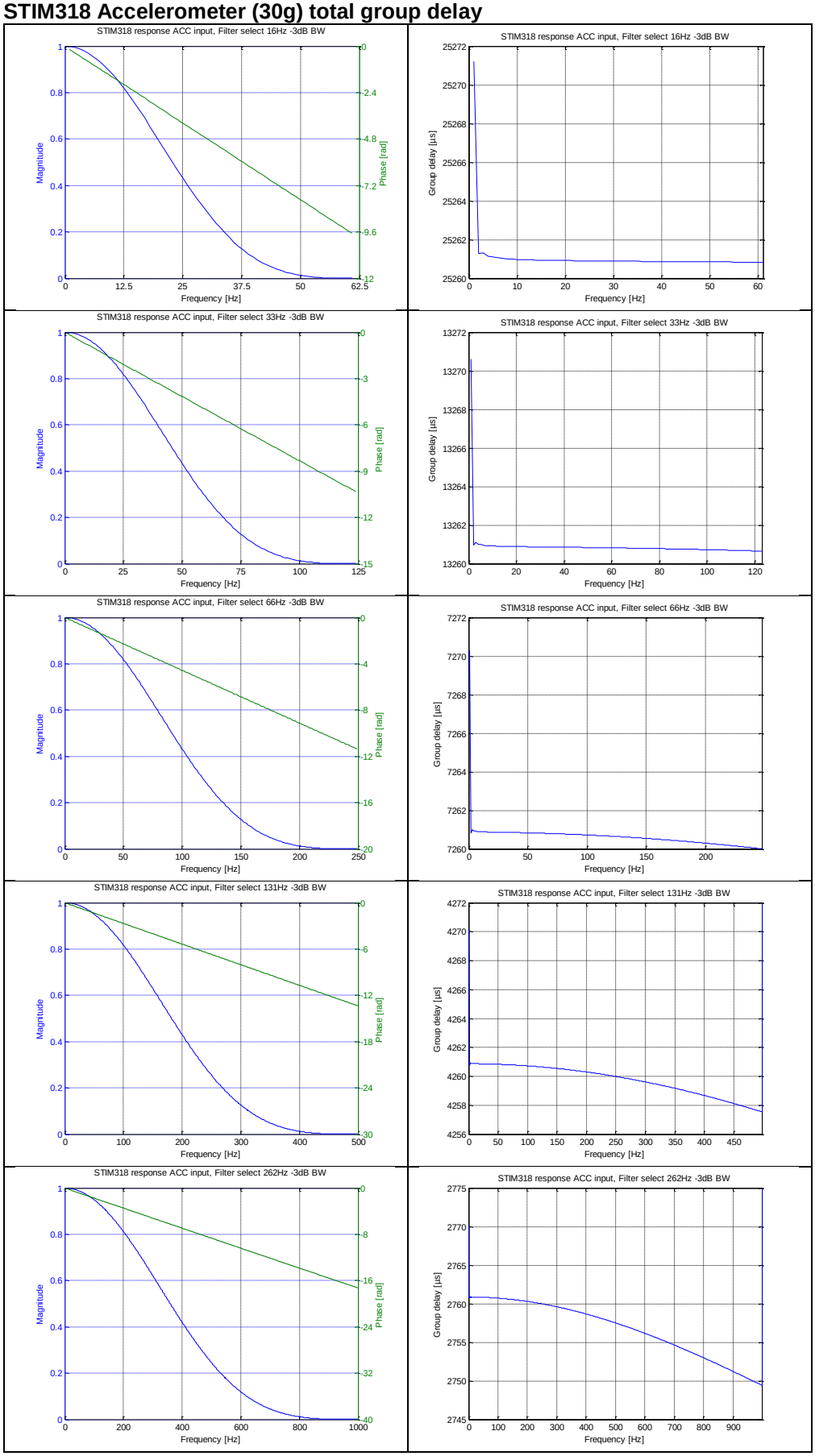

Figure C-8: STIM318 Accelerometer (30g) total amplitude response (left) and total group delay (right)

STIM318 Accelerometer (80g) total group delay

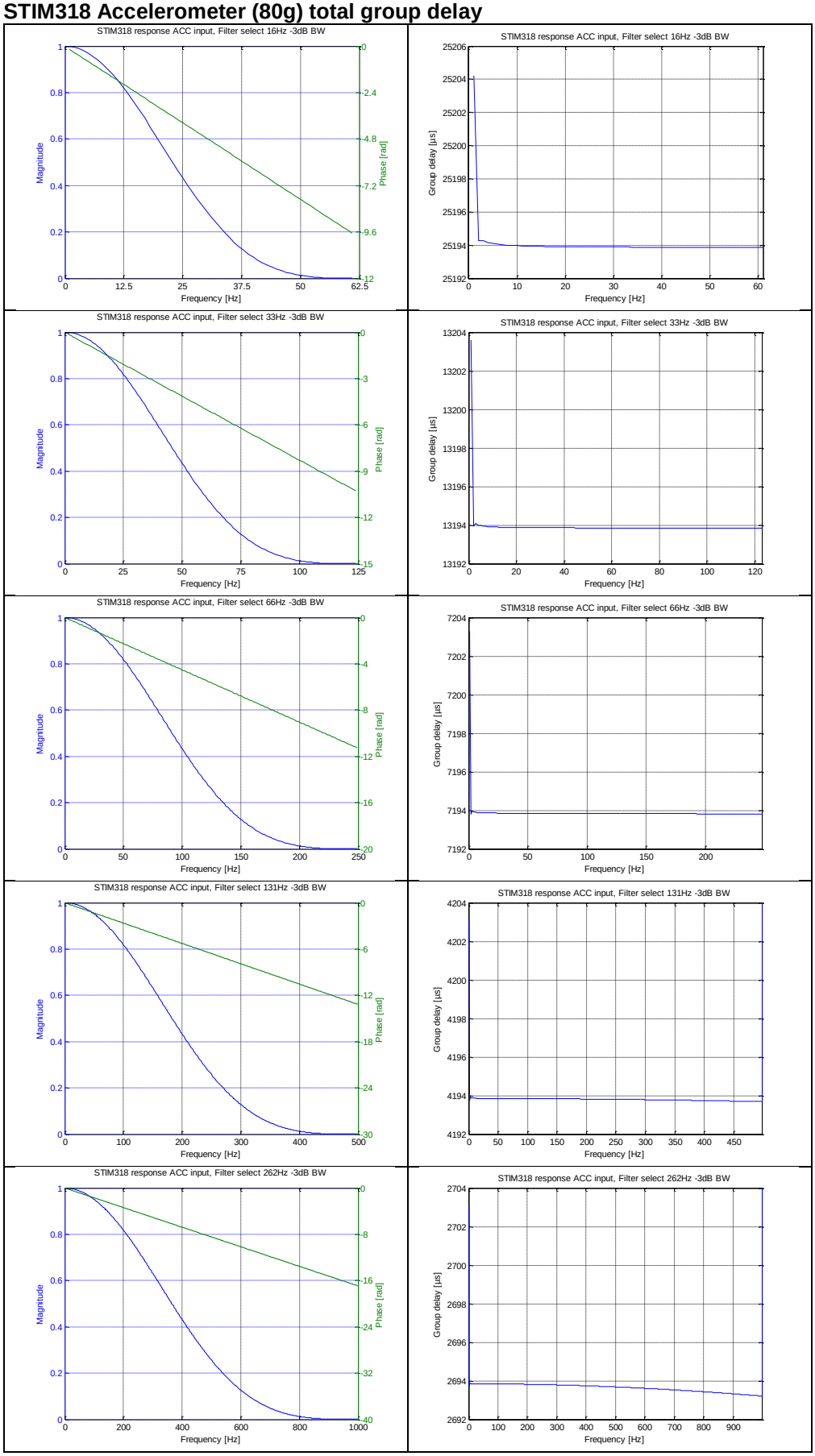

Figure C-9: STIM318 Accelerometer (80g) total amplitude response (left) and total group delay (right)

STIM318 Inclinometer total group delay

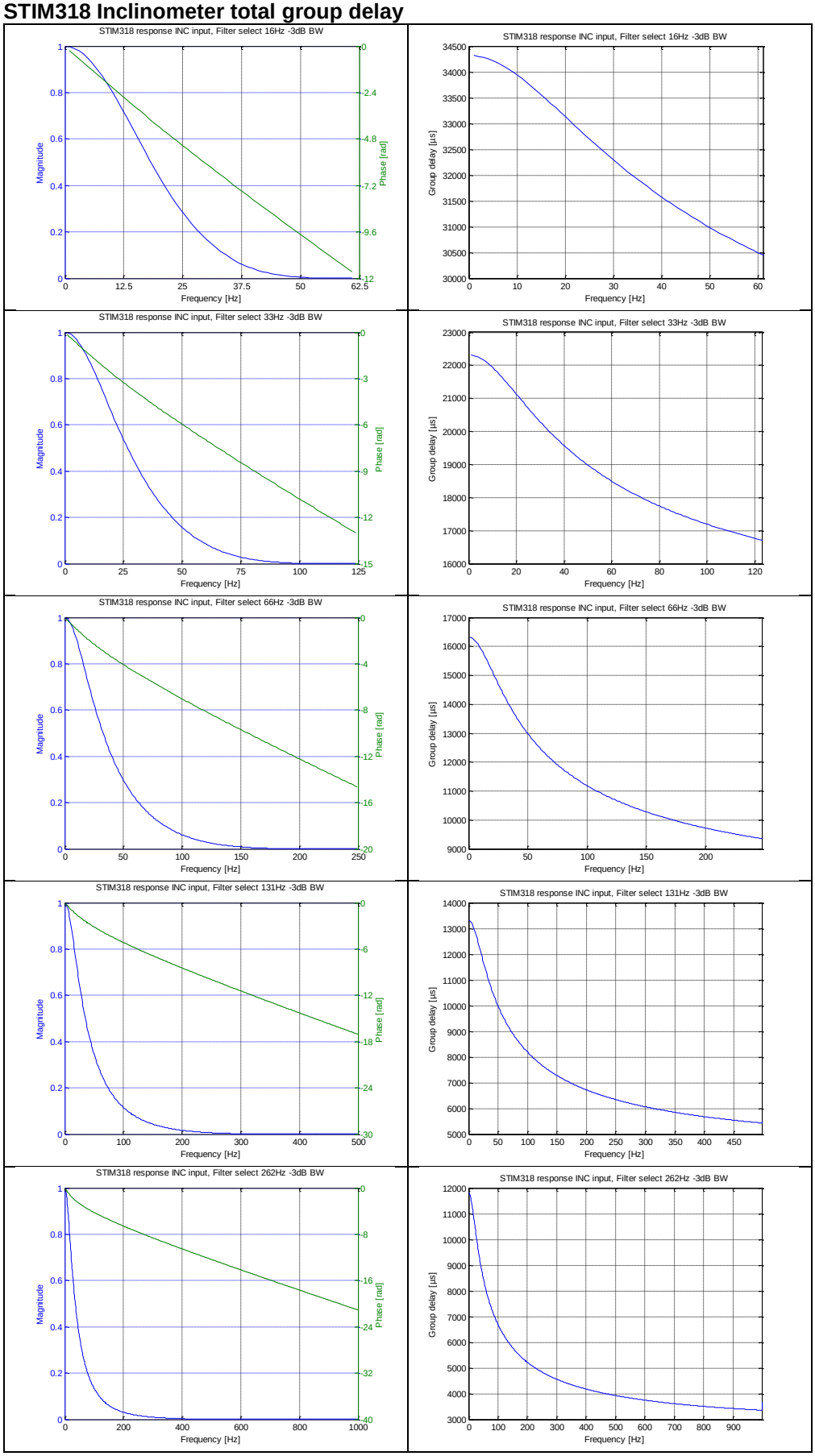

Figure C-10: STIM318 Inclinometer total amplitude response (left) and total group delay (right)

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