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.

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## 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.

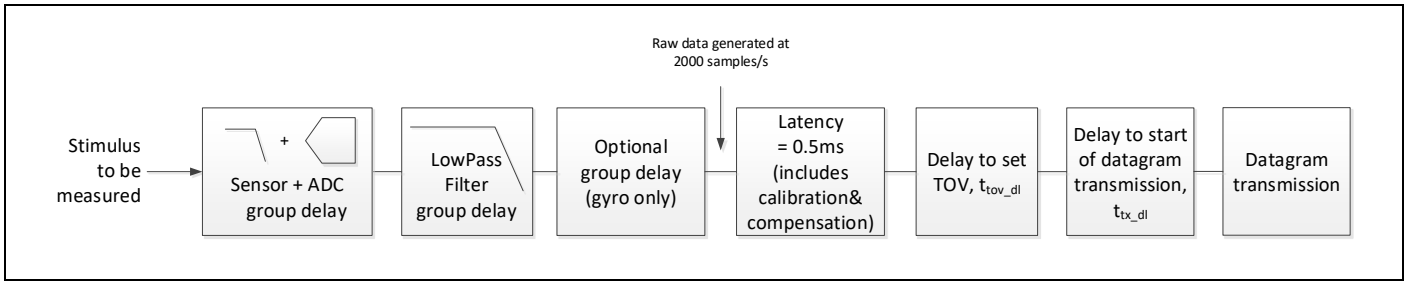


**Figure 2-1: Time delays when sampling rate is not set to "External Trigger"**

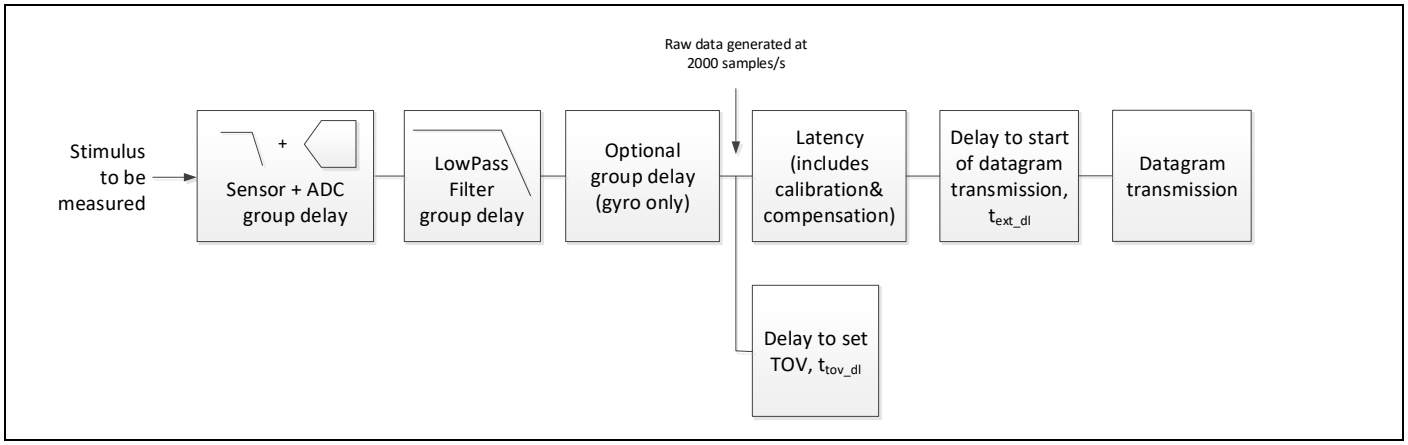


**Figure 2-2: Time delays when sampling rate set to "External Trigger"**

## 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 | Sensor + ADC group delay STIM318 |
|---|---|---|
| Gyro | 0.71ms | 0.71ms |
| Accelerometer, 5g | 5.19ms | 1.62ms |
| Accelerometer, 10g | 5.19ms | 1.51ms |
| Accelerometer, 30g | 6.03ms | 1.31ms |
| Accelerometer, 80g | 5.22ms | 1.24ms |
| Inclinometer | 13.8ms | - |
| 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) = -0.05ms for gyros and -0.19ms for other sensors
LPFDelayOffset (STIM318) = -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 | LowPass Filter group delay, other sensors STIM318 |
|---|---|---|---|
| 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 1.0ms for STIM318 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 STIM300 datasheet (TS1524) or STIM318 datasheet (TS1657) 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 STIM300 datasheet (TS1524) or STIM318 datasheet (TS1657) 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 STIM318 respectively. Details of each sensor can be found in the preceding sub-chapters.

**Table 3-1: Summary of total group delays STIM300**

| 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**

| 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 |

## 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, 1.0ms for STIM318
- $t_{tov_dl}$: ref. section 2.5 and STIM300 Datasheet, TS1524, or STIM318 Datasheet, TS1657
- $t_{tx_dl}$: ref. section 2.6 and STIM300 Datasheet, TS1524, or STIM318 Datasheet, TS1657
- #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. STIM300 Datasheet, TS1524, or STIM318 Datasheet, TS1657
- #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<br>Angular rate - delayed | Acceleration | Acceleration | Voltage | 1 |
| Incremental angle<br>Average angular rate<br>Incremental angle – delayed<br>Average angular rate - delayed | Incremental velocity<br>Average acceleration | Incremental velocity<br>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, 1.0ms for STIM318
- Latency: latency value in datagram, ref. section 2.4 and STIM300 Datasheet, TS1524 or STIM318 Datasheet TS1657
- $t_{tov_dl}$: ref. section 2.5 and STIM300 Datasheet (TS1524) or STIM318 Datasheet (TS1657)
- $t_{ext_dl}$: ref. section 2.6 and STIM300 Datasheet (TS1524) or STIM318 Datasheet (TS1657)
- #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. STIM300 Datasheet, TS1524, or STIM318 Datasheet, TS1657
- #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<br>Angular rate - delayed | Acceleration | Acceleration | Voltage | 1 |
| Incremental angle<br>Average angular rate<br>Incremental angle – delayed<br>Average angular rate - delayed | Incremental velocity<br>Average acceleration | Incremental velocity<br>Average acceleration | Not Applicable | If $counter_n > counter_{n-1}$:<br>$\#samples = counter_n - counter_{n-1}$<br><br>If $counter_n < counter_{n-1}$:<br>$\#samples = 256 + counter_n - counter_{n-1}$<br><br>where<br>• $counter_n$ is the counter-value of the current datagram<br>• $counter_{n-1}$ 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

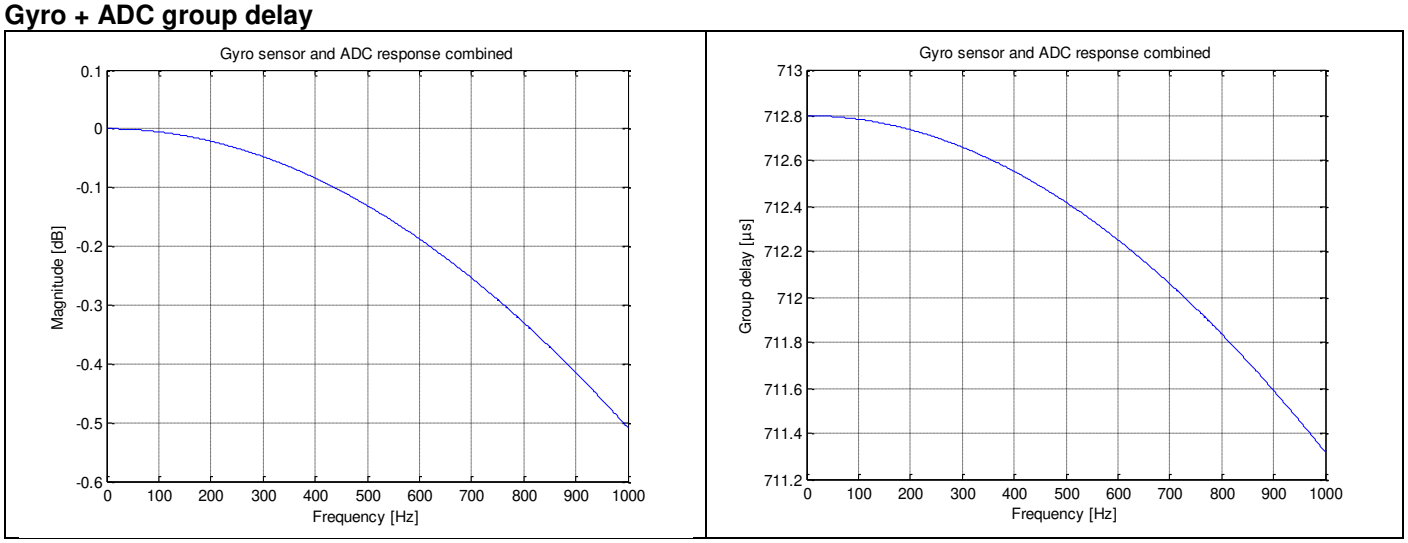


**Figure A-1: Gyro + ADC amplitude response (left) and group delay (right)**

### STIM300 Accelerometer (5g+10g) + ADC group delay

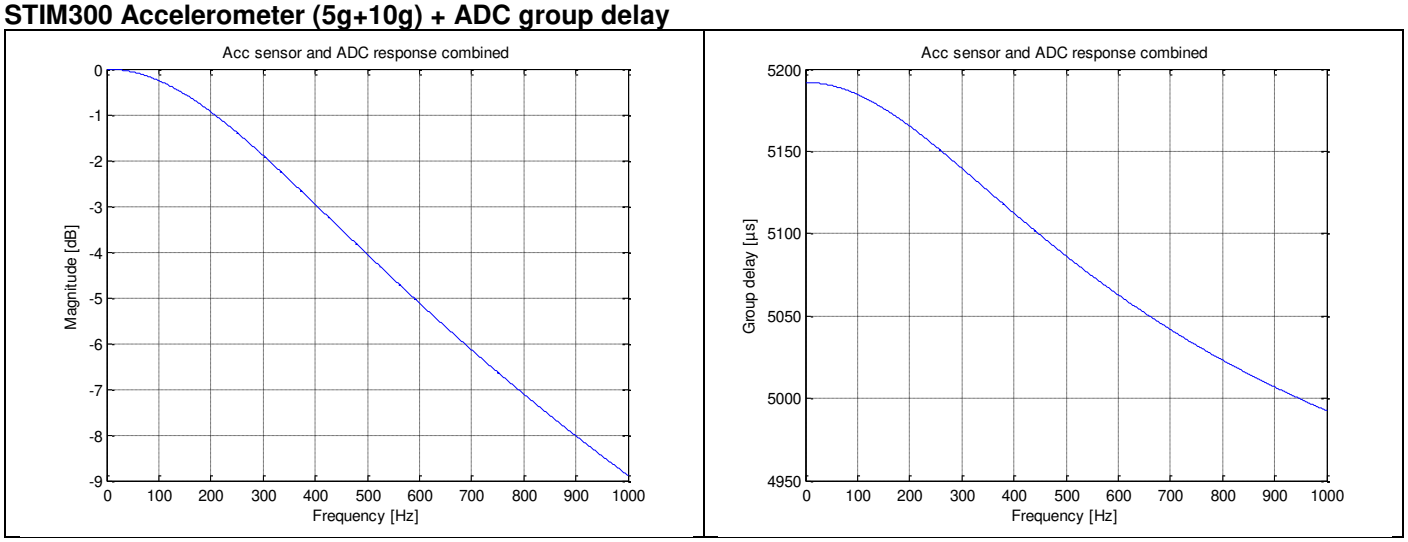


**Figure A-2: STIM300 Accelerometer (5g + 10g) + ADC amplitude response (left) and group delay (right)**

### STIM300 Accelerometer (30g) + ADC group delay

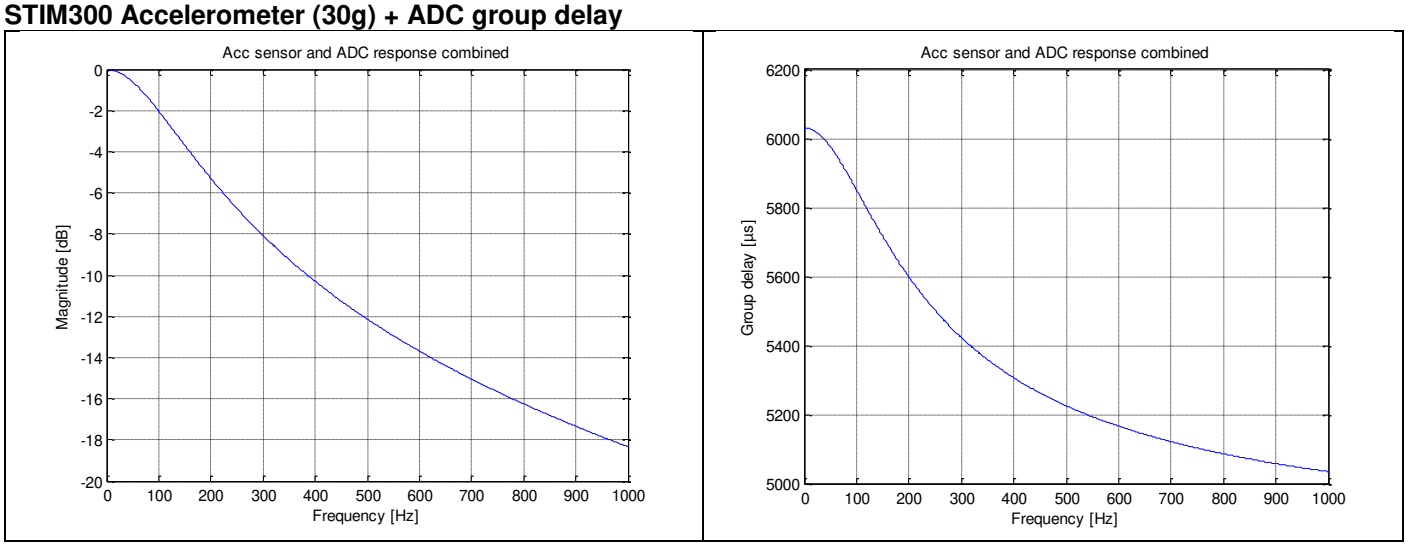


**Figure A-3: STIM300 Accelerometer (30g) + ADC amplitude response (left) and group delay (right)**

**STIM300 Accelerometer (80g) + ADC group delay**

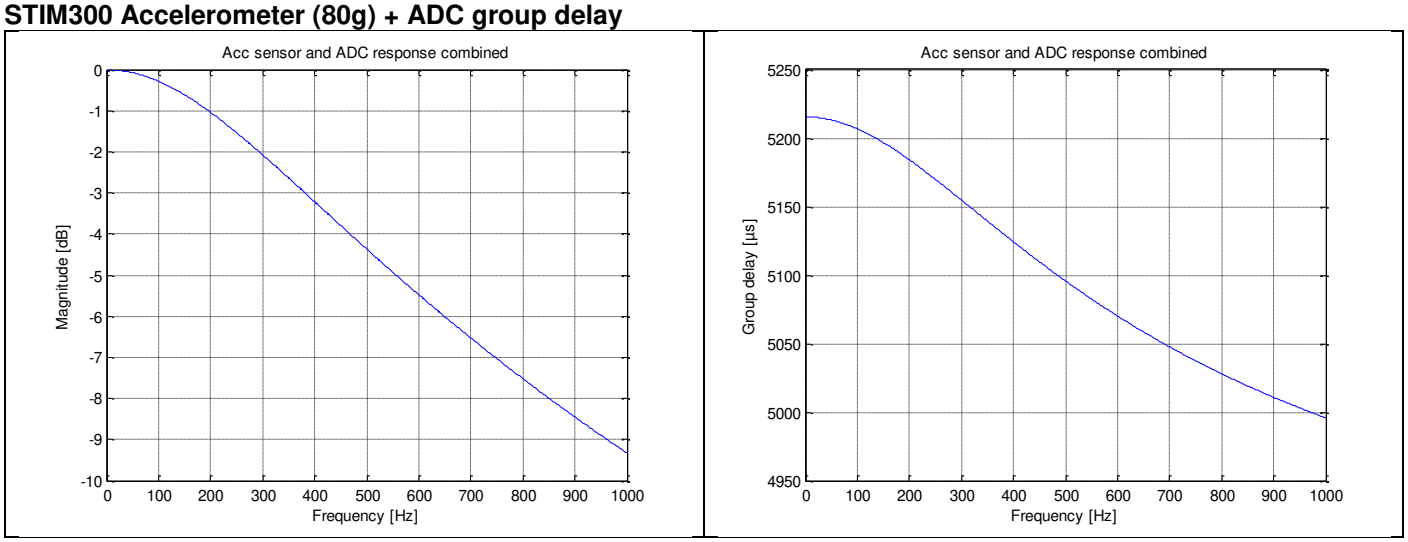


**Figure A-4: STIM300 Accelerometer (80g) + ADC amplitude response (left) and group delay (right)**

**STIM300 Inclinometer + ADC group delay**

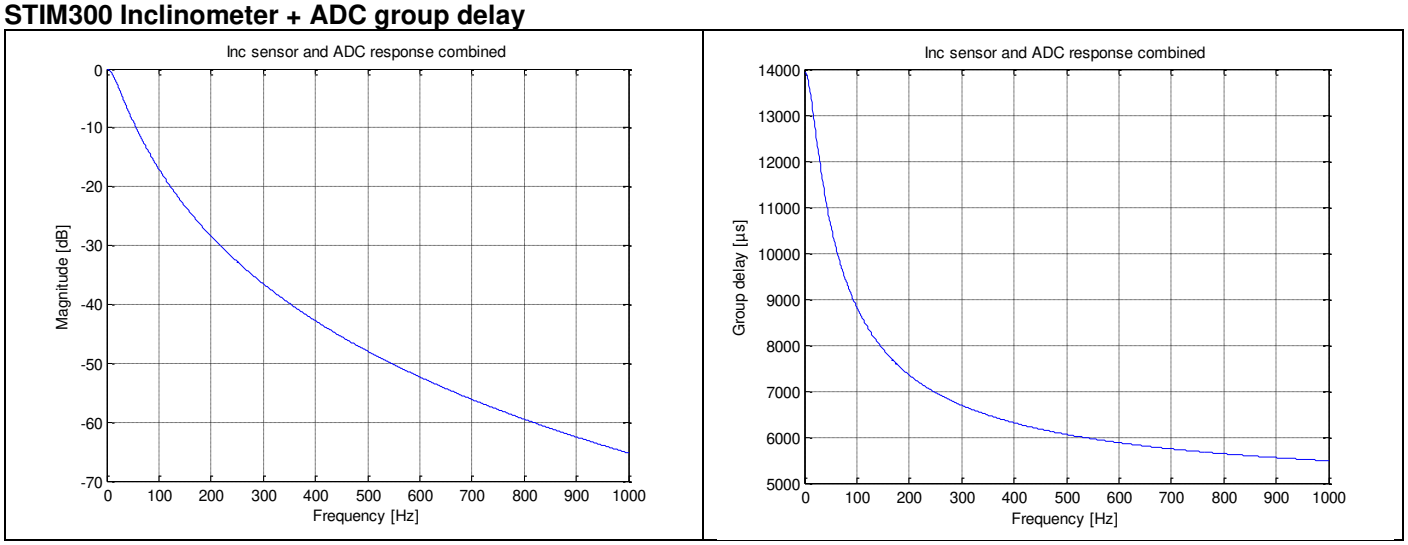


**Figure A-5: STIM300 Inclinometer + ADC amplitude response (left) and group delay (right)**

**STIM300 AUX + ADC group delay**

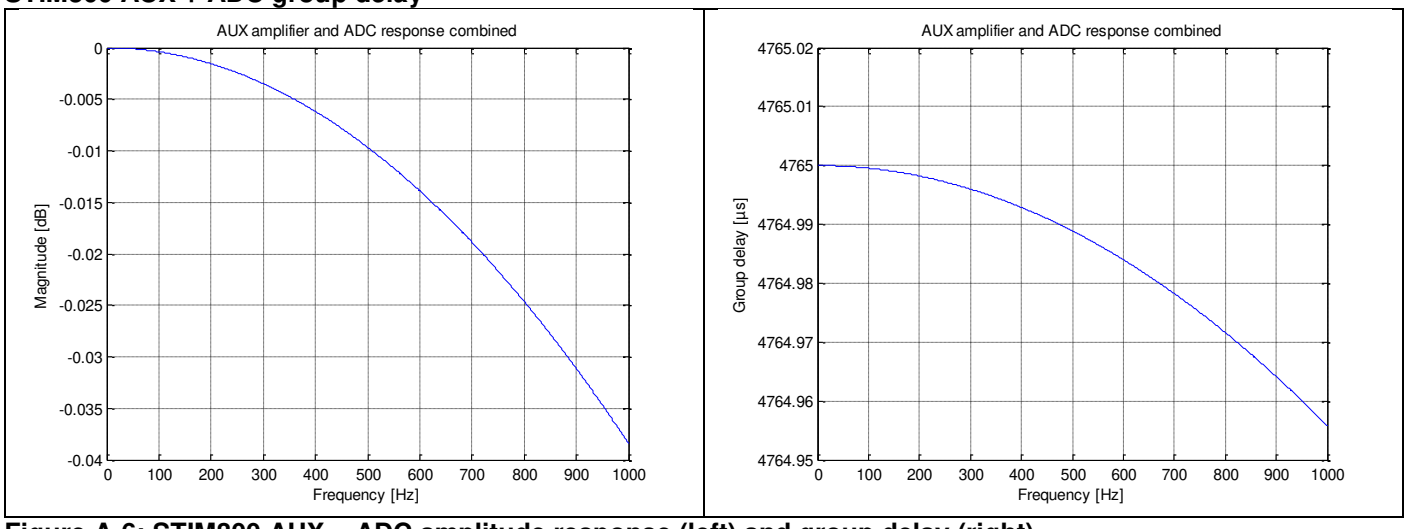


**Figure A-6: STIM300 AUX + ADC amplitude response (left) and group delay (right)**

**STIM318 Accelerometer (5g) + ADC group delay**

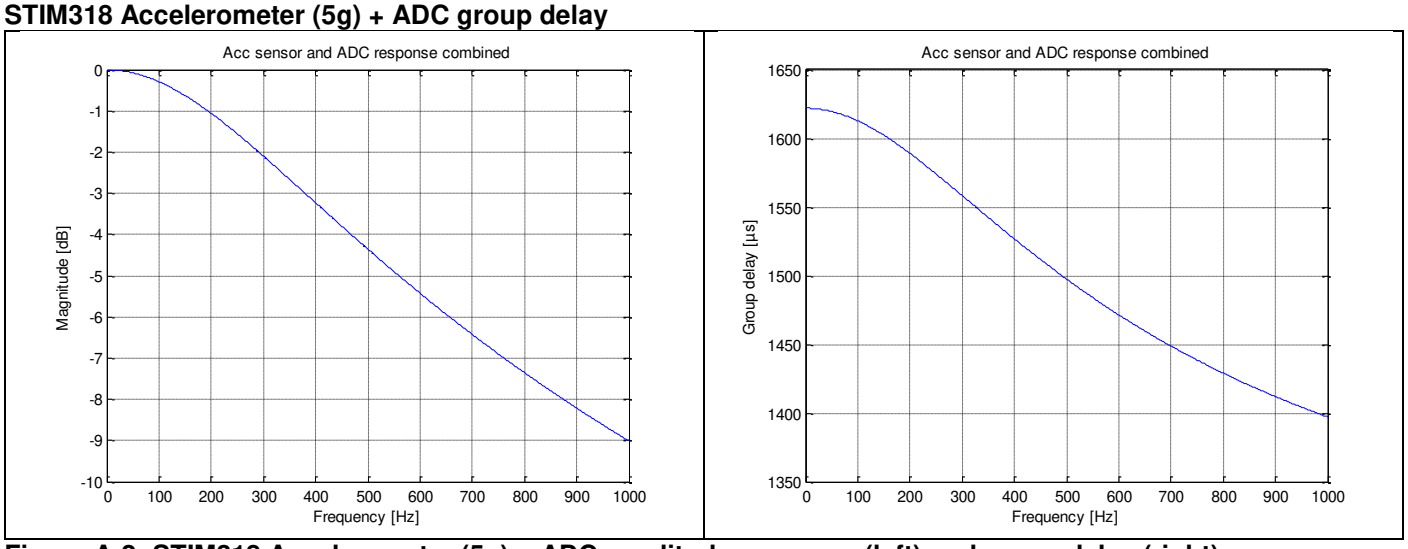


**Figure A-2: STIM318 Accelerometer (5g) + ADC amplitude response (left) and group delay (right)**

**STIM318 Accelerometer (10g) + ADC group delay**

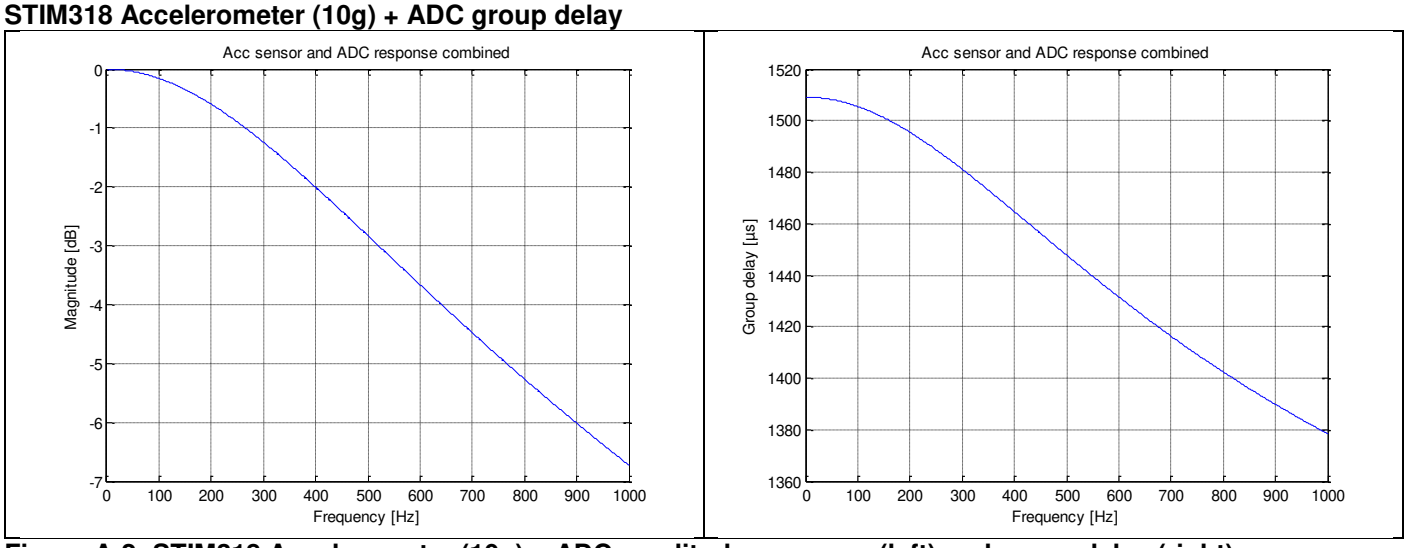


**Figure A-2: STIM318 Accelerometer (10g) + ADC amplitude response (left) and group delay (right)**

**STIM318 Accelerometer (30g) + ADC group delay**

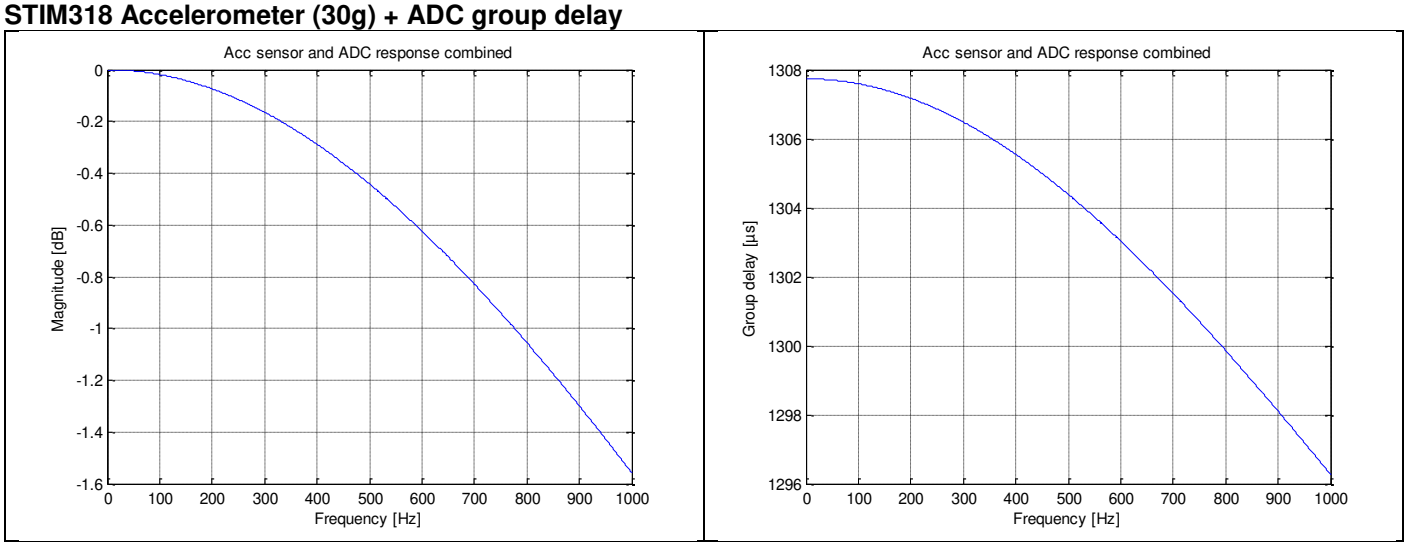


**Figure A-3: STIM318 Accelerometer (30g) + ADC amplitude response (left) and group delay (right)**

**STIM318 Accelerometer (80g) + ADC group delay**

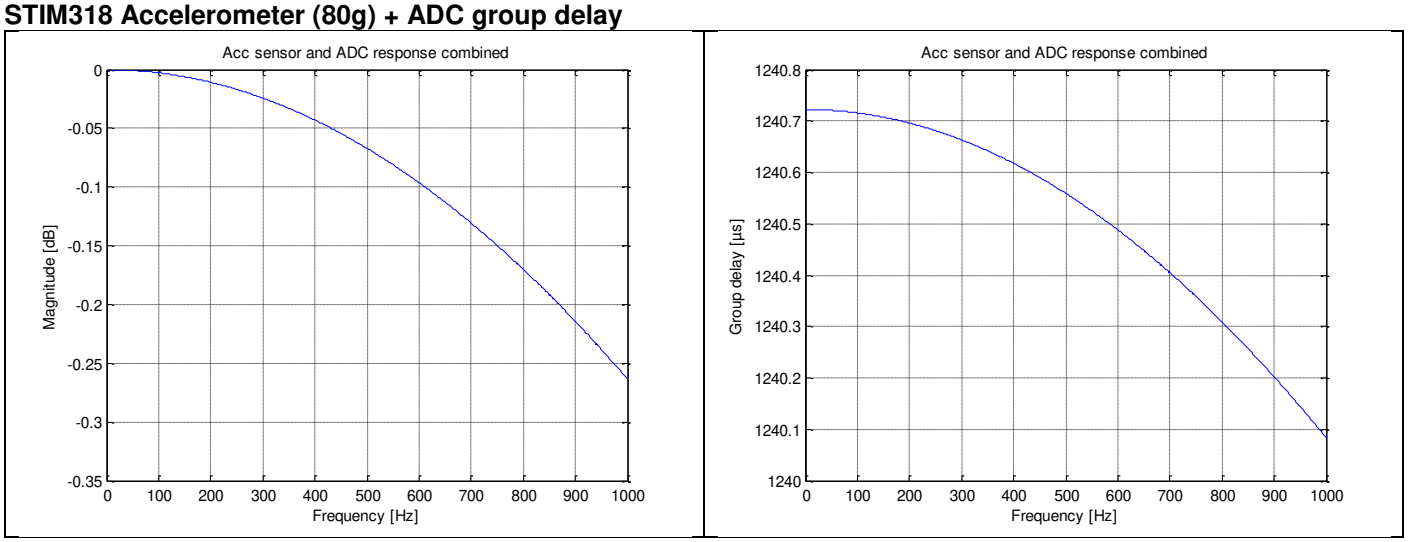


**Figure A-4: STIM318 Accelerometer (80g) + ADC amplitude response (left) and group delay (right)**

## APPENDIX B: Plots of LowPassFilter group delays

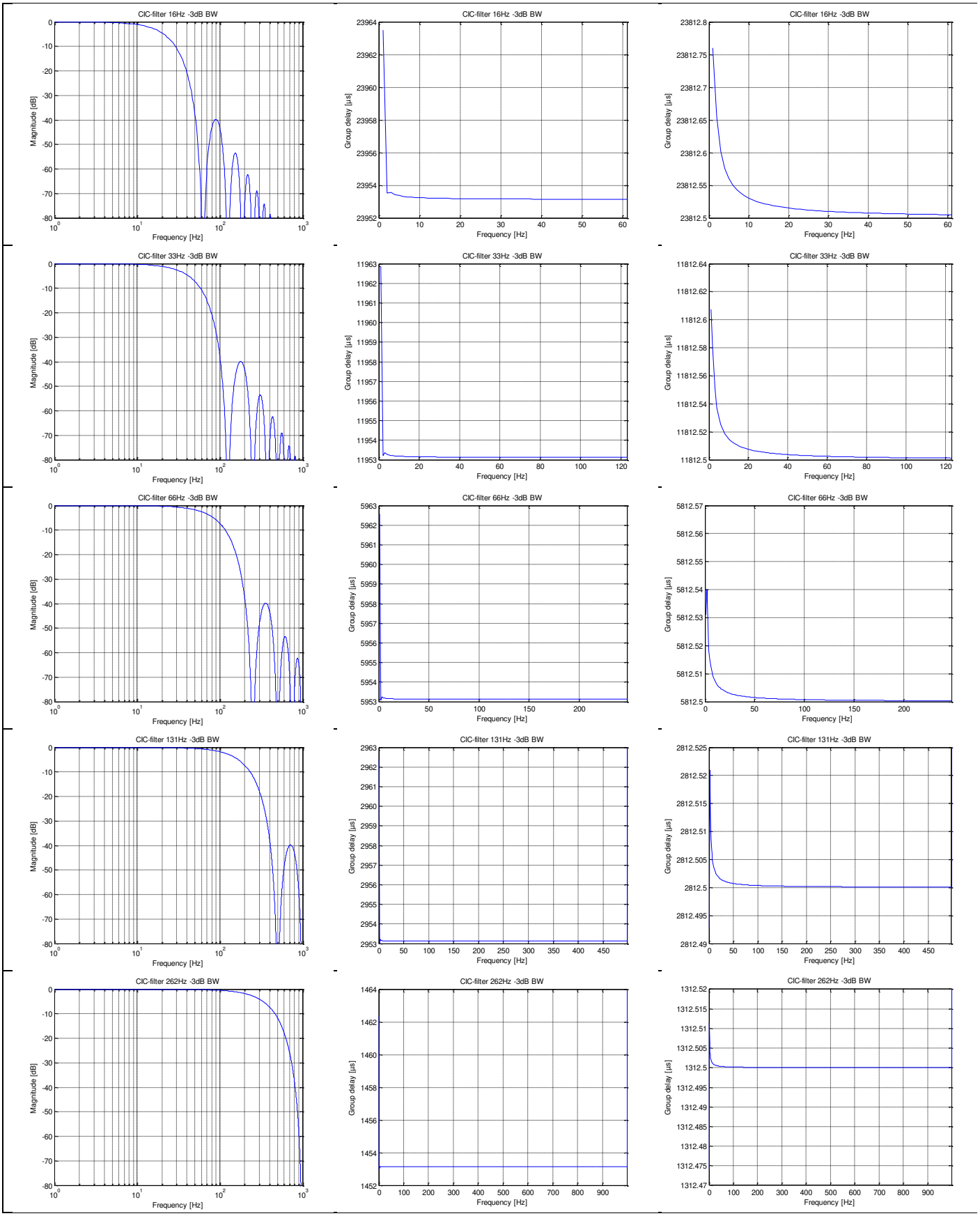


**Figure B-1: STIM300: LowPass Filter amplitude response (left), group delay - gyros (middle) and group delay – others (right)**

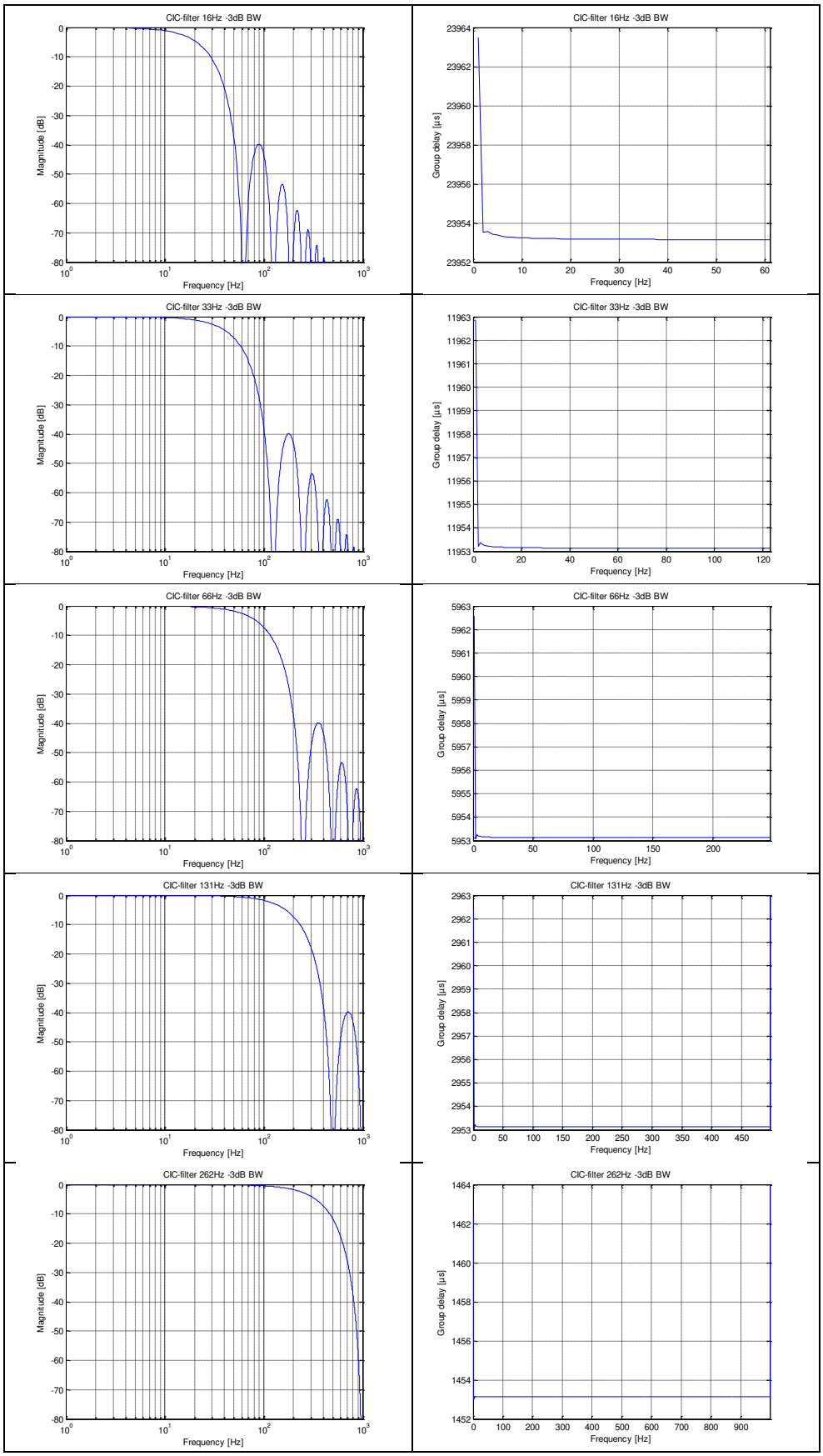


**Figure B-2: STIM318: LowPass Filter amplitude response (left), group delay (right)**

## APPENDIX C: Plots of total sensor group delays

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

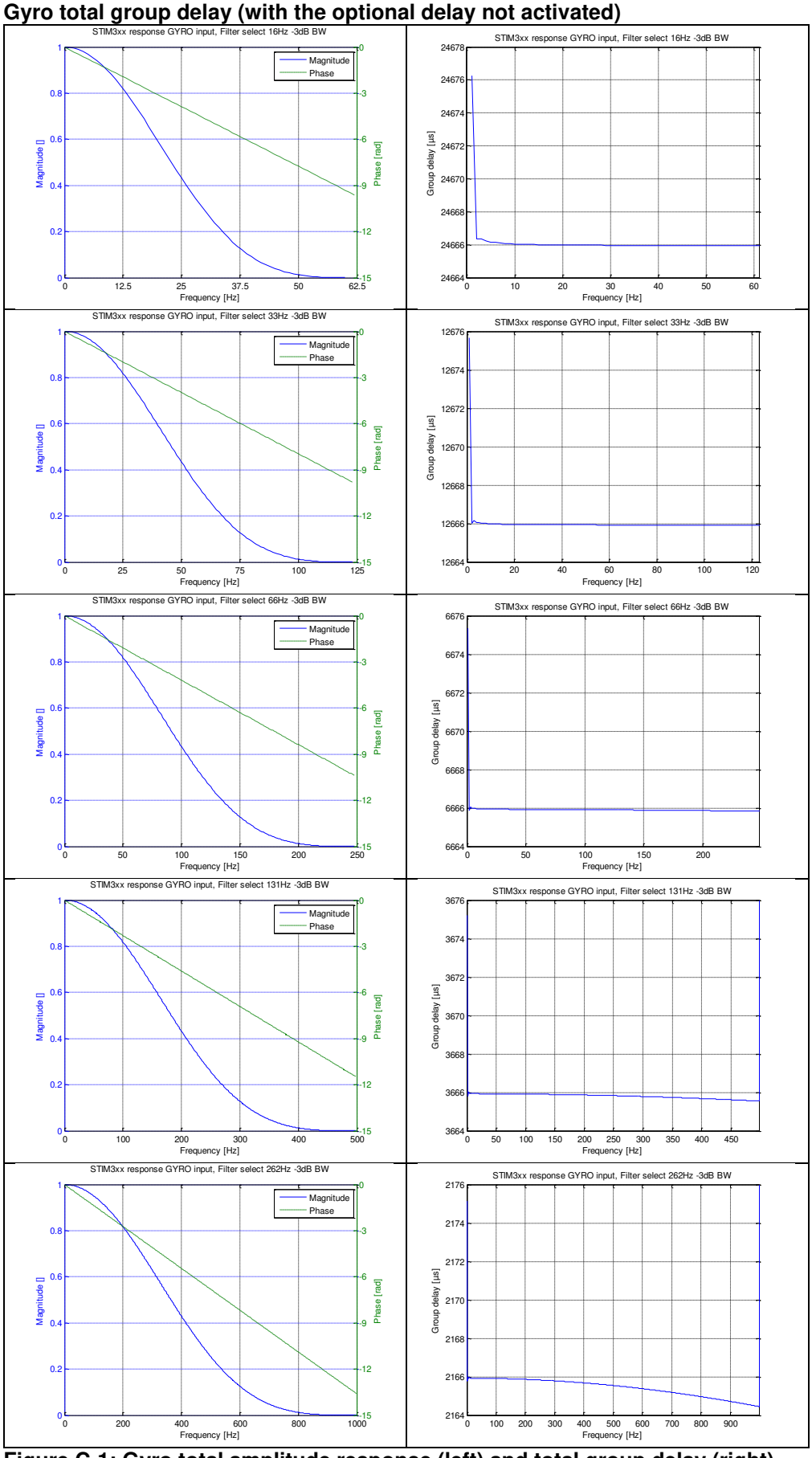


**Figure C-1: Gyro total amplitude response (left) and total group delay (right)**

## STIM300 Accelerometer (5g+10g) total group delay

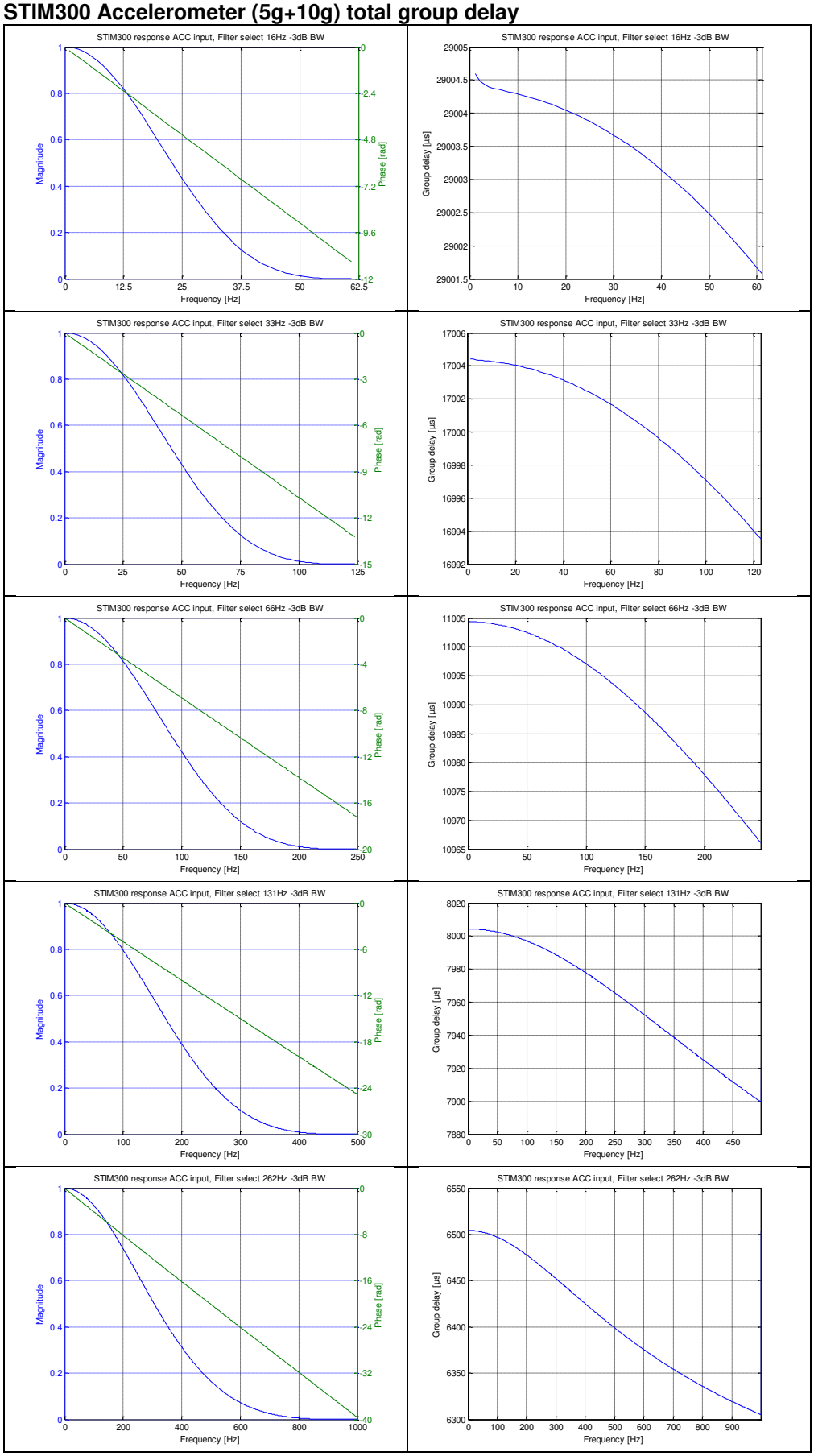


**Figure C-2: STIM300 Accelerometer (5g+10g) total amplitude response (left) and total group delay (right)**

**STIM300 Accelerometer (30g) total group delay**

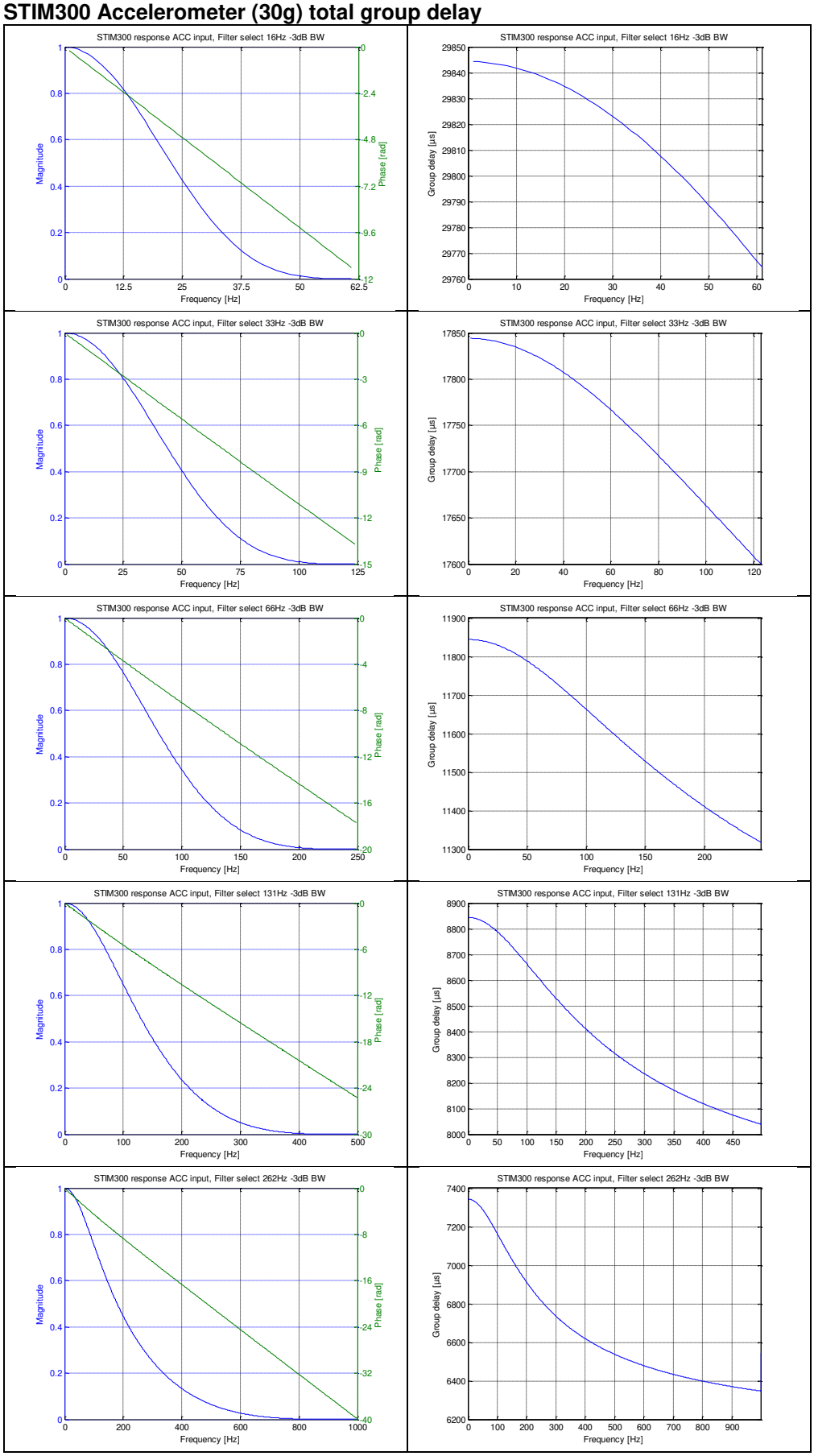


**Figure C-3: STIM300 Accelerometer (30g) total amplitude response (left) and total group delay (right)**

## STIM300 Accelerometer (80g) total group delay

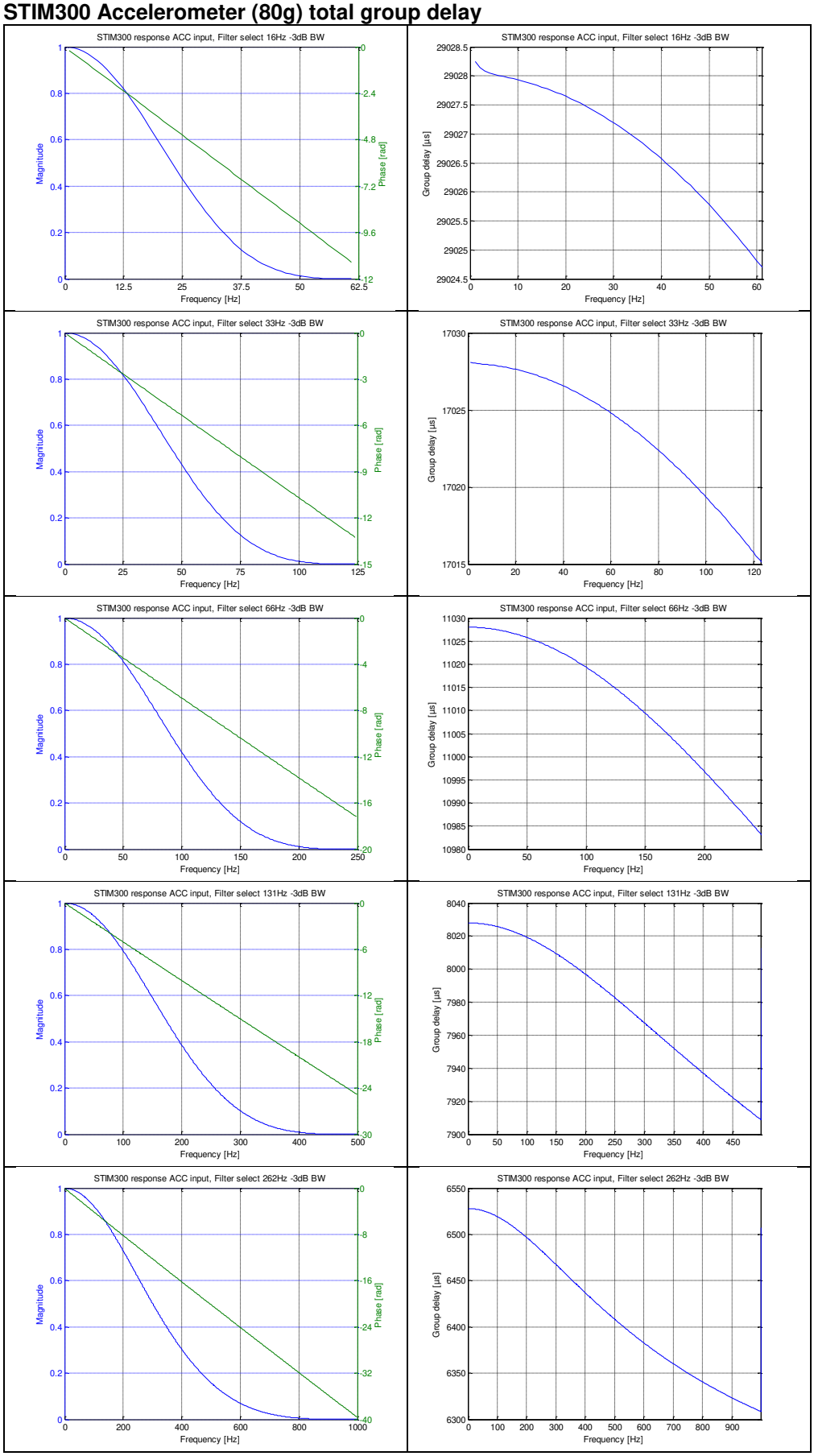


**Figure C-4: STIM300 Accelerometer (80g) total amplitude response (left) and total group delay (right)**

## STIM300 Inclinometer total group delay

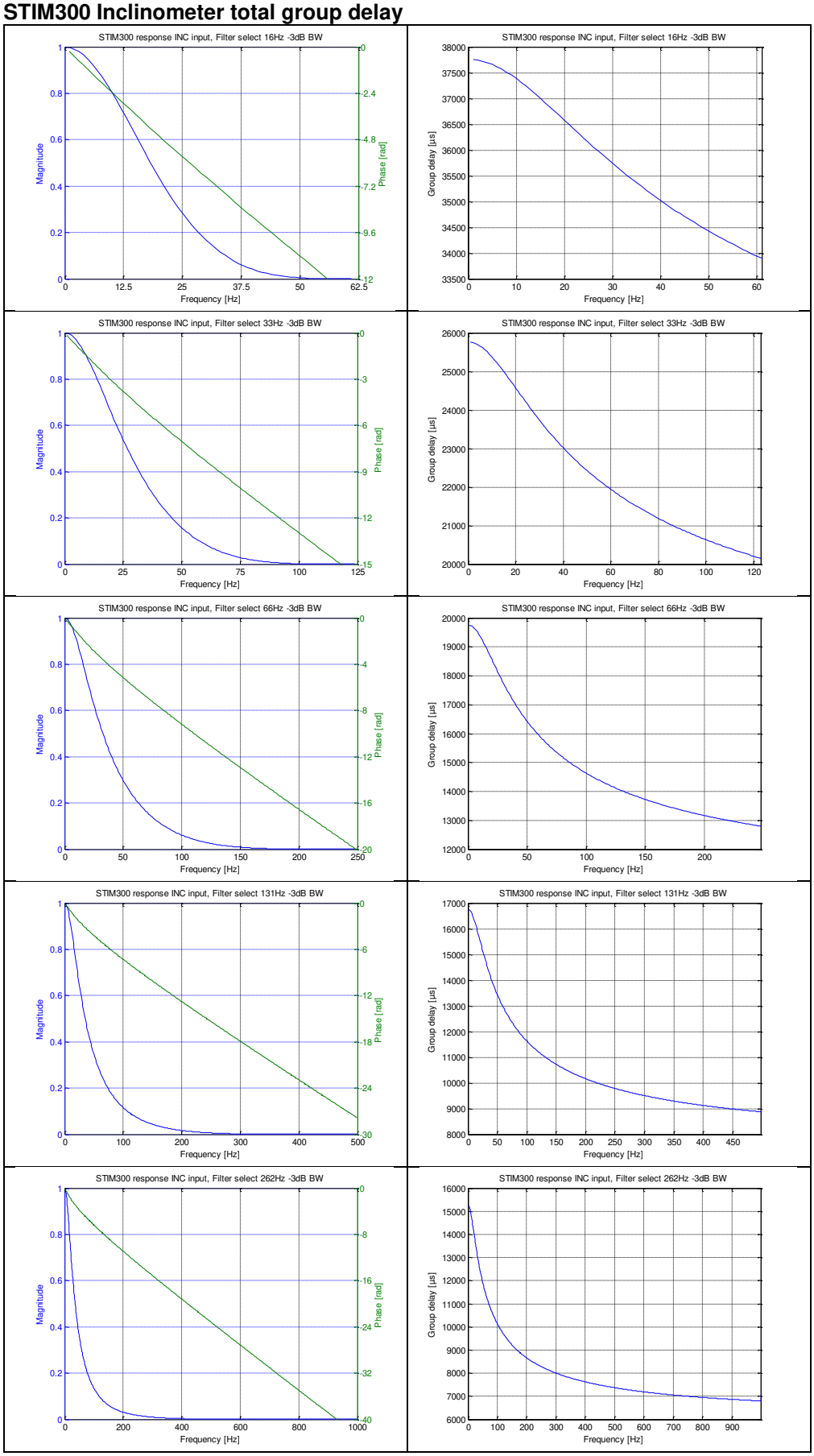


**Figure C-5: STIM300 Inclinometer total amplitude response (left) and total group delay (right)**

## STIM300 AUX total group delay

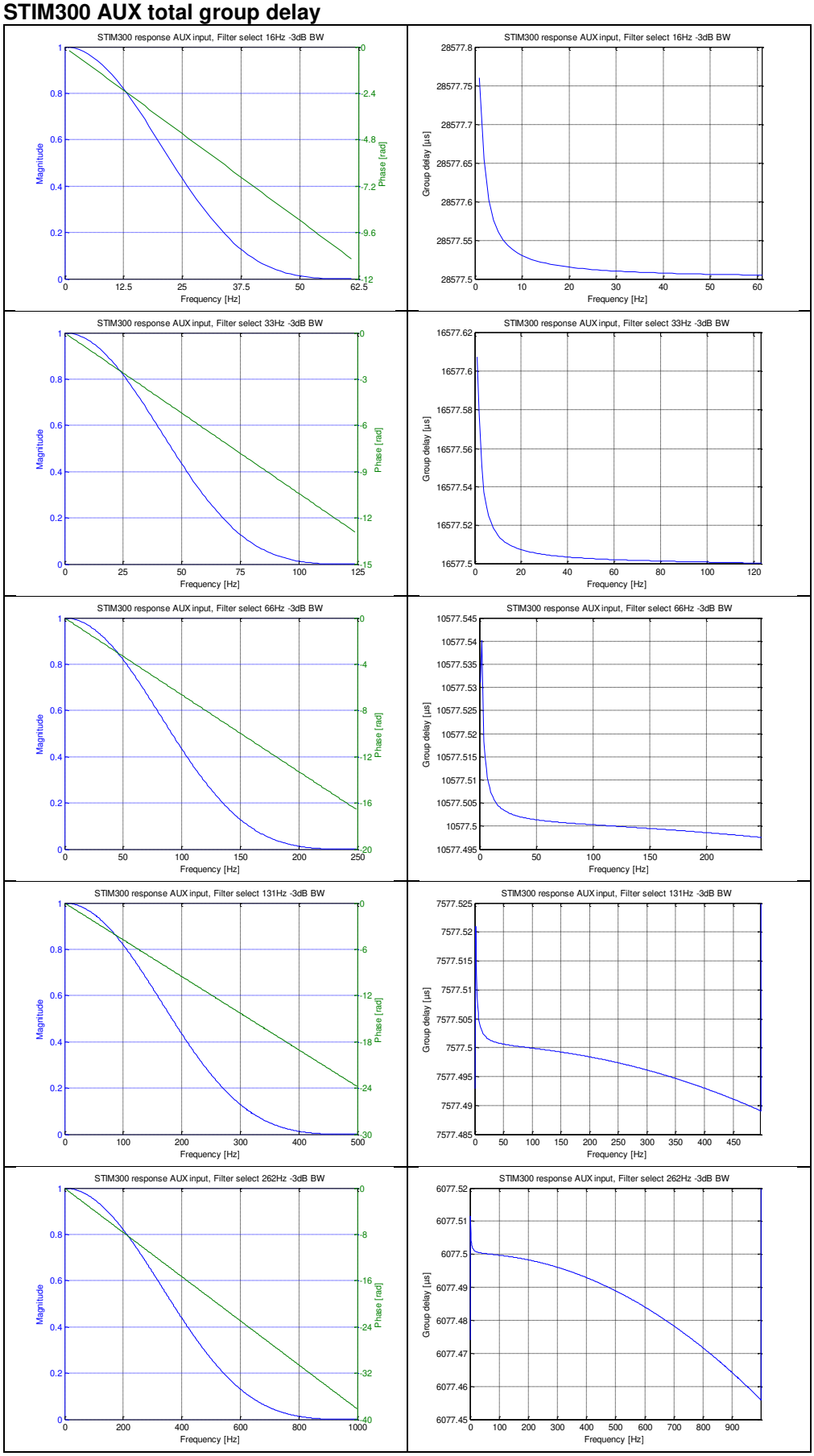


**Figure C-6: STIM300 AUX total amplitude response (left) and total group delay (right)**

## STIM318 Accelerometer (5g) total group delay

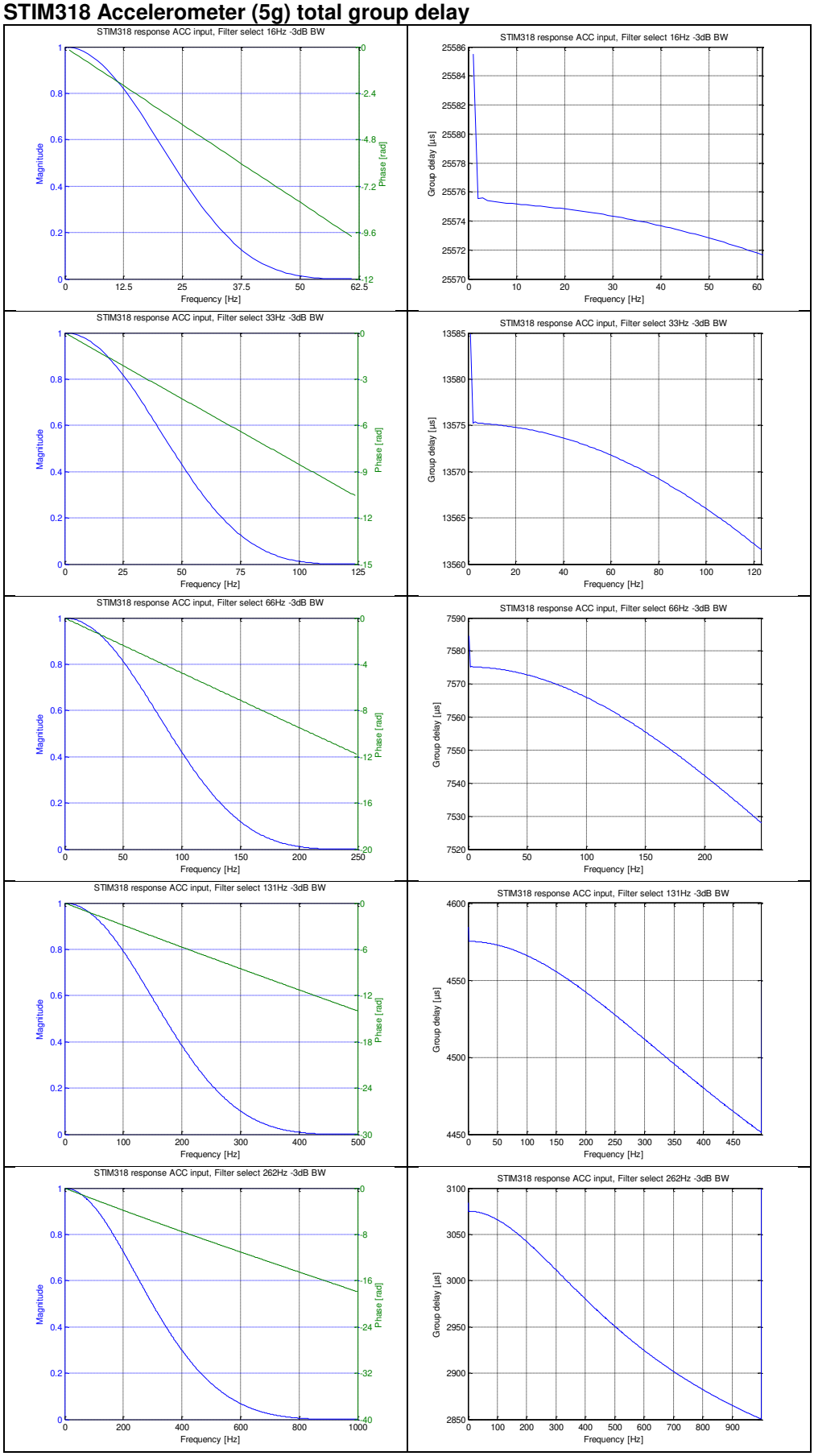


**Figure C-7: STIM318 Accelerometer (5g) total amplitude response (left) and total group delay (right)**

## STIM318 Accelerometer (10g) total group delay

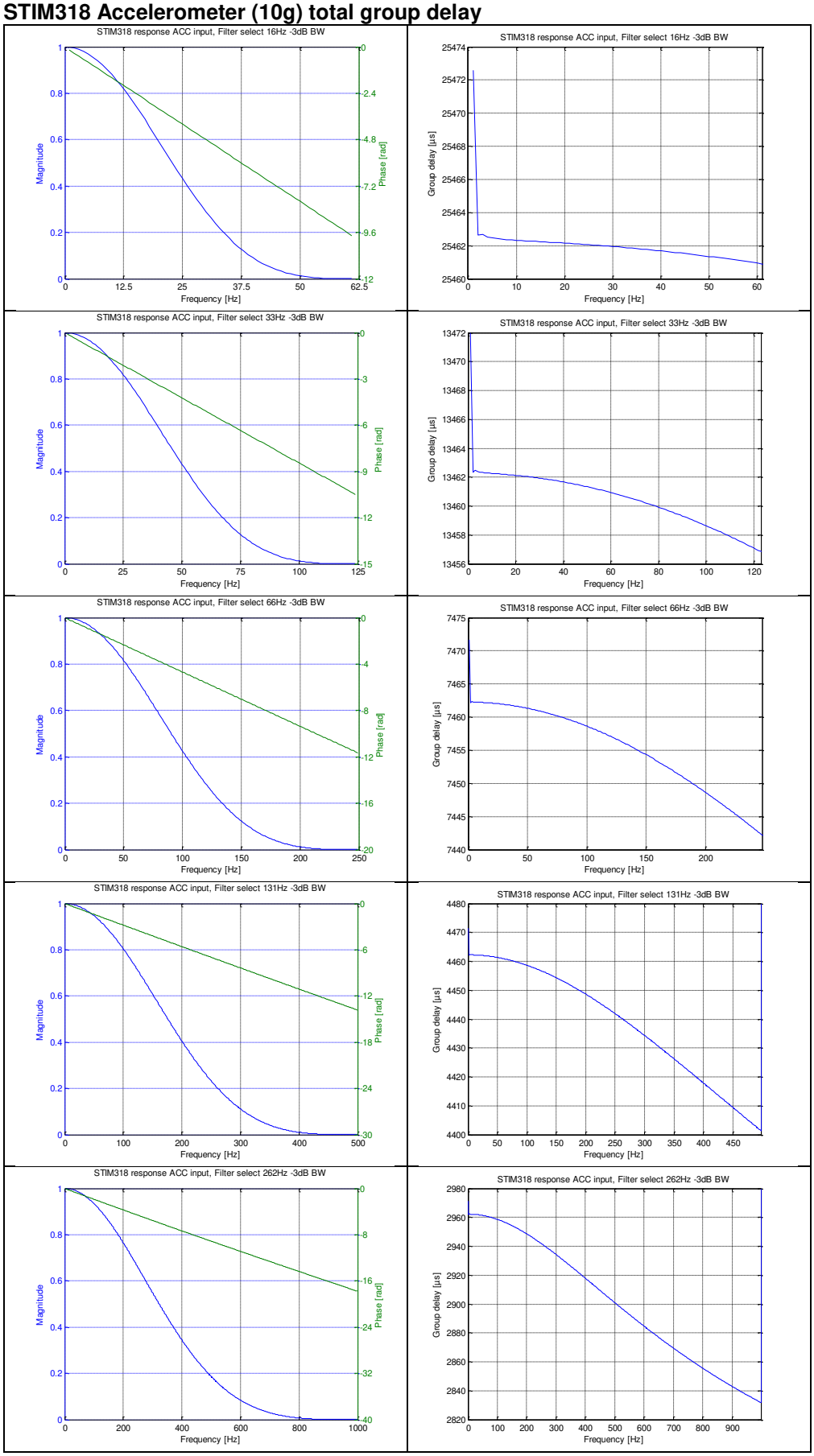


**Figure C-8: STIM318 Accelerometer (10g) total amplitude response (left) and total group delay (right)**

## STIM318 Accelerometer (30g) total group delay

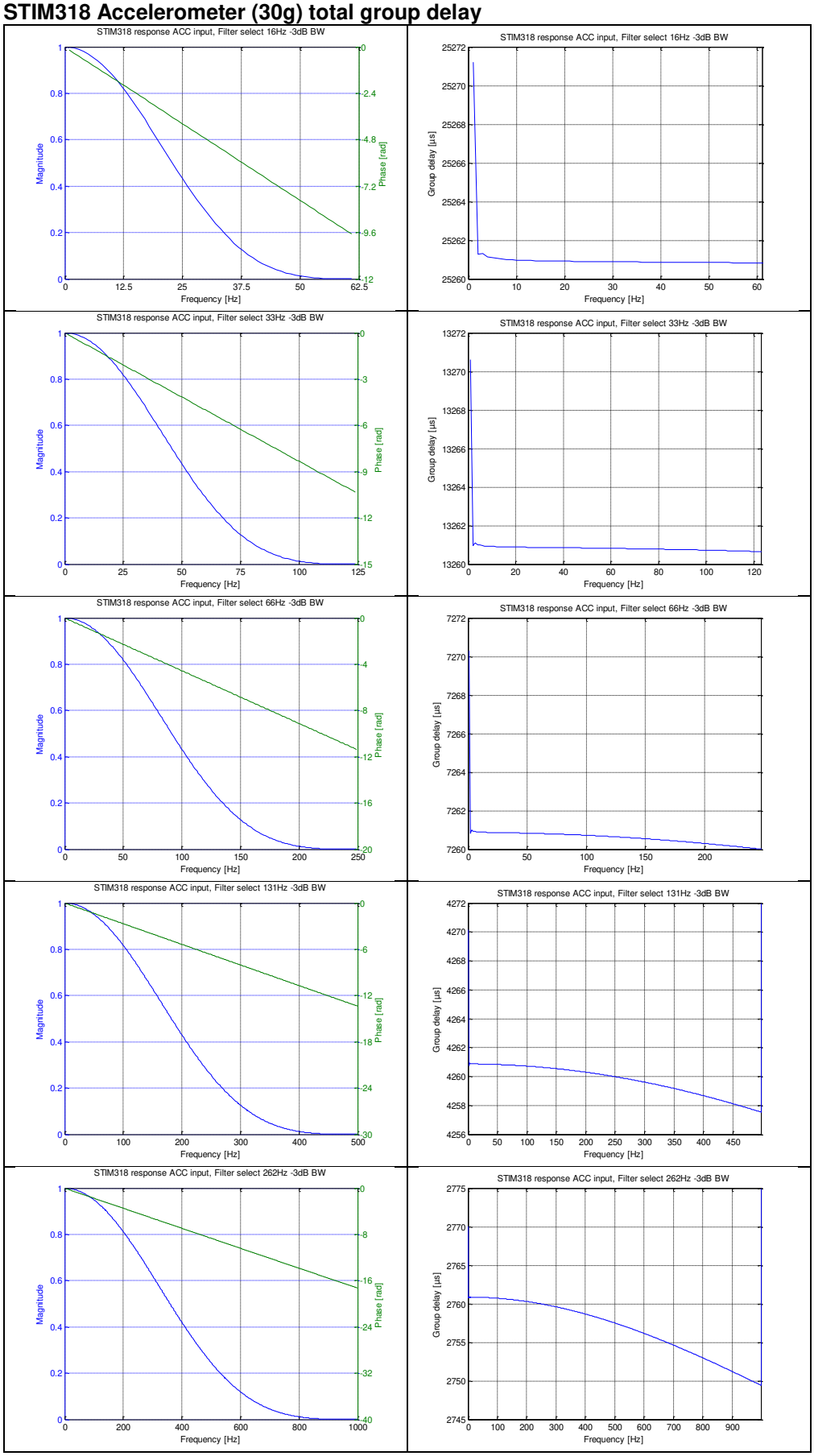


**Figure C-9: STIM318 Accelerometer (30g) total amplitude response (left) and total group delay (right)**

## STIM318 Accelerometer (80g) total group delay

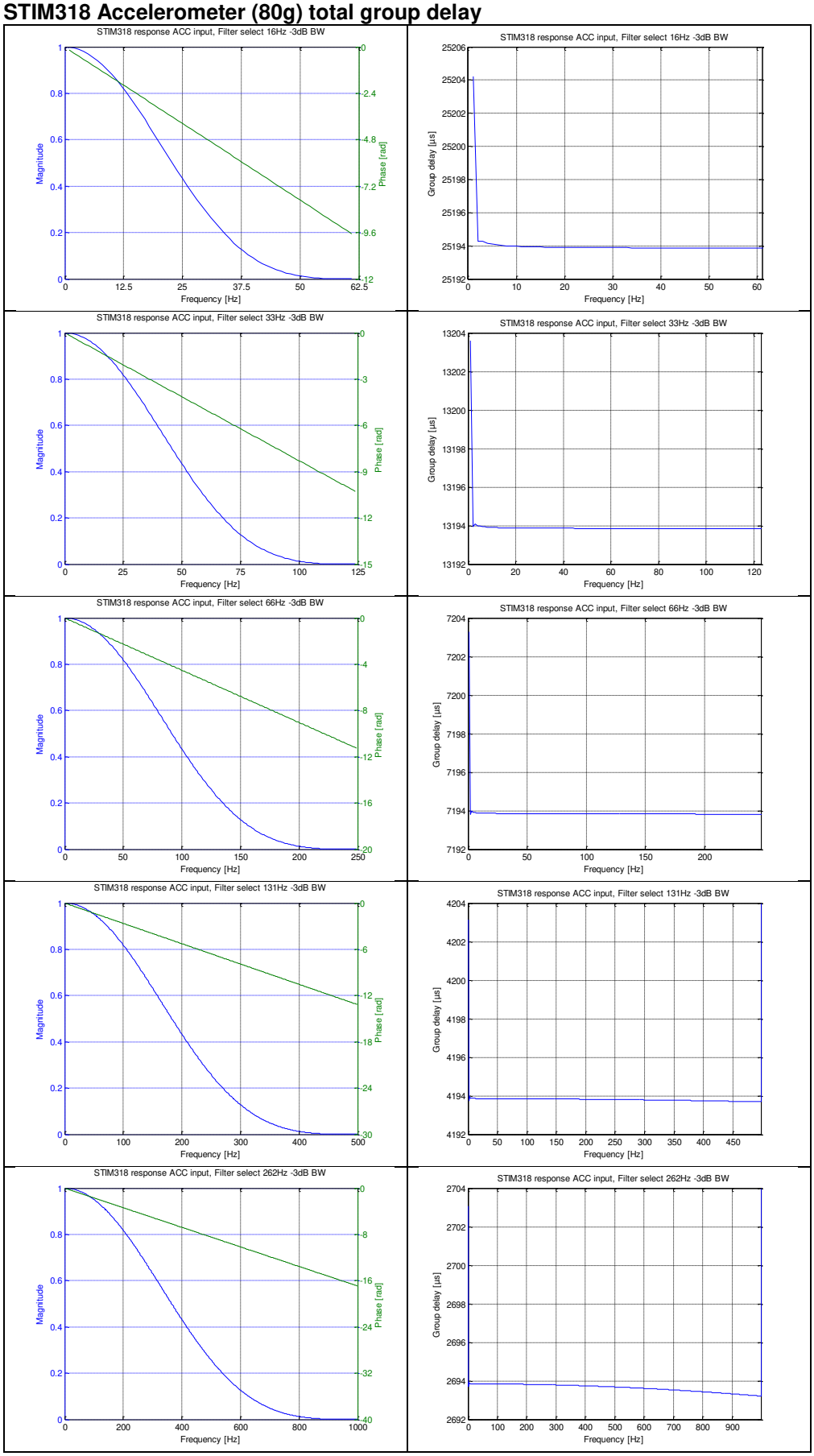


**Figure C-10: STIM318 Accelerometer (80g) total amplitude response (left) and total group delay (right)**

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