# Application Note:
Waveform averaging

The ADQ digitizers are equipped with real time firmware support for waveform averaging. This document describes the different averaging functions that are available, and how they should be configured.

Introduction

One common way of reducing system noise and increase sensitivity is to repeat a measurement several time and study the average signal. This method reduces the non-correlated noise and increases the correlated wanted signal. The method of waveform[1] averaging result in large amount of measurement data. In order to reduce the load on the host computer, the ADQ series digitizers include support for waveforms accumulation in the on-board FPGA. The FPGA implementation of waveform averaging enables real time accumulation of waveforms which speeds up the measurement.

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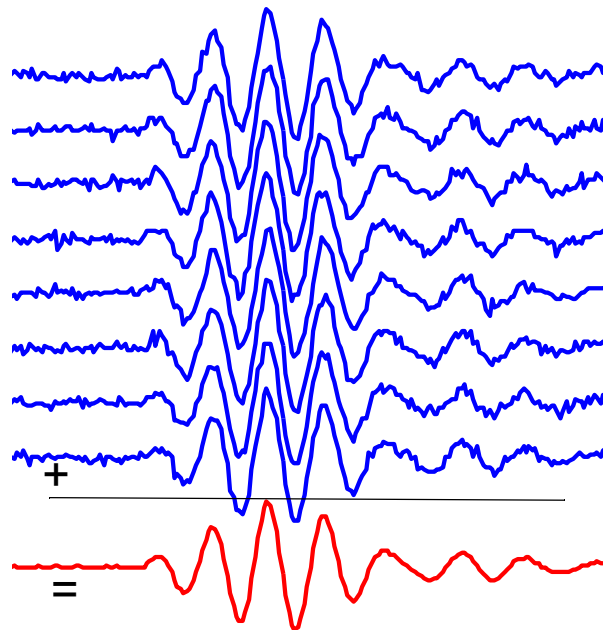
1. A waveform is a sequential set of data following a trigger event. In some literature, this data set is called record.

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1 Waveform Averaging Functional Description

1.1 Algorithm

A waveform is defined as a series of consecutive samples. The averaging algorithm calculates the average of a set of M waveforms. For each sample, n, the average value Y_n is calculated as in **(1)**.

$$Y_n = (X_{1,n} + X_{1,n} + X_{1,n} + ... + X_{M,n}) / M \tag{1}$$

The FPGA firmware implementation only contains accumulation. The division operation in the averaging algorithm is seldom required in the application and is left to the user to implement in software. The hardware operation is (see **Figure 1**):

1. read from the accumulator

2. add the ADC sample

3. write the result to the accumulator

4. repeat for the next sample.

The operation is repeated until the end of the waveform. The system waits for next trigger and then starts the process of accumulating the next waveform.

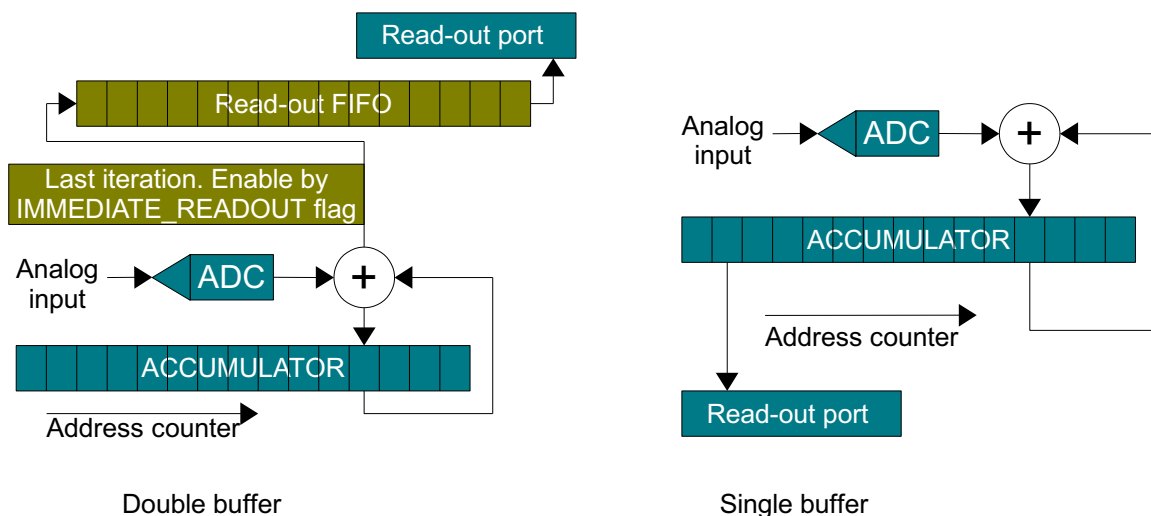When all waveforms are accumulated, data is read by the host PC.

Double buffer   Single buffer

Figure 1: WFA block diagram

1.2 Implementation

The block diagram of the accumulator is in **Figure 1**. Addition is done in the sample rate of the ADC. The accumulators are 32 bit. The accumulator is a RAM (not FIFO).

Between the waveforms, there is a re-arm time that has to be considered when scheduling the operation.

After the last waveform, the last result has to be read out to the host PC before a new acquisition may start. This rearm time may be longer. If the unit support double buffering, the re-arm time for a new accumulation is the same as between waveforms. Double buffering has a sep-

arate read-out FIFO, to which data is written at the last accumulation. Enable double buffer by setting the flag for immediate read out, see **Table 3**.

See **Table 1** for parameters for each digitizer model.

1.3 Block diagram ADQ V5

Figure 2 shows the location of the Waveform Averaging block in the first FPGA of the ADQ V5 digitizer family. Default mode of the digitizer is to bypass the Waveform Averaging block. The second FPGA contains the host interface.
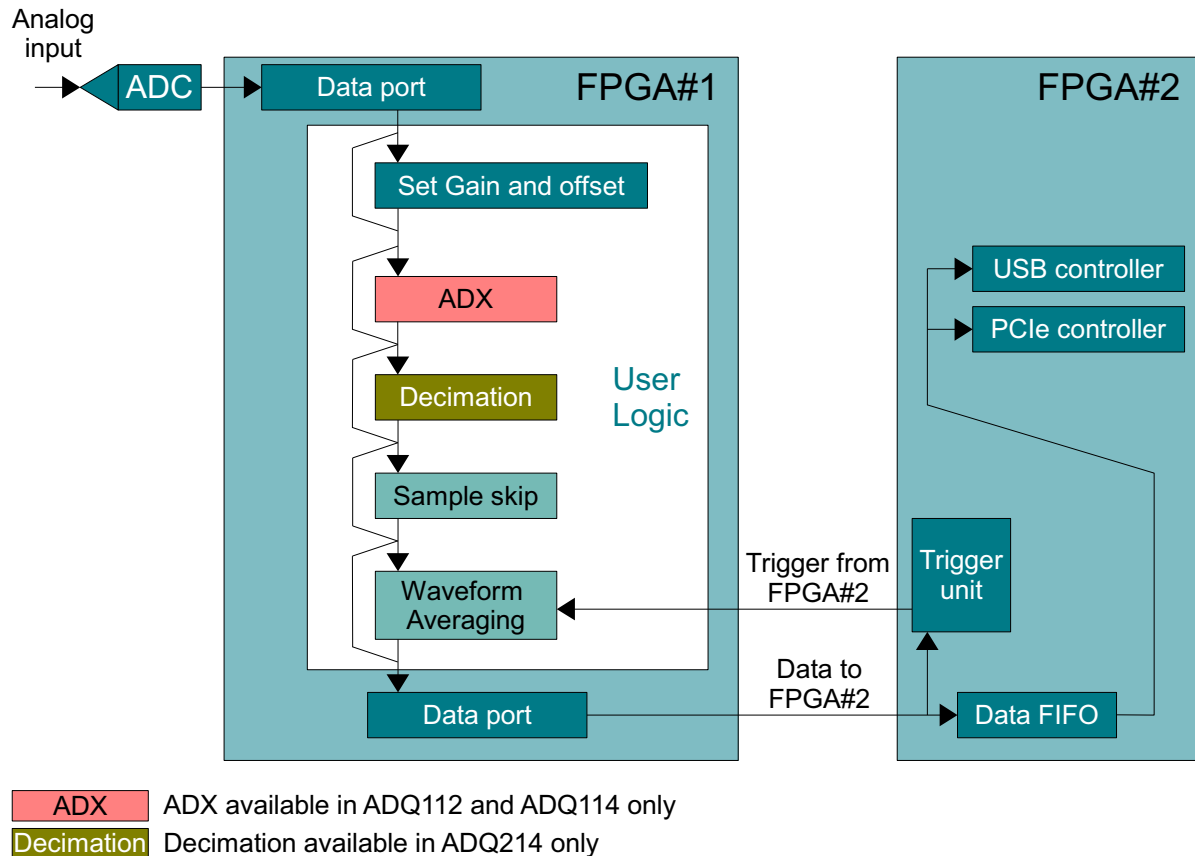
ADX   ADX available in ADQ112 and ADQ114 only
Decimation   Decimation available in ADQ214 only

Figure 2: ADQ V5 digitizer family; FPGA#1 block diagram placing the WFA

1.4 Block diagram ADQ V6

Figure 3 shows the location of the Waveform Averaging block in the FPGA of the ADQ V6 digitizer family. Default mode of the digitizer is to bypass the Waveform Averaging block.
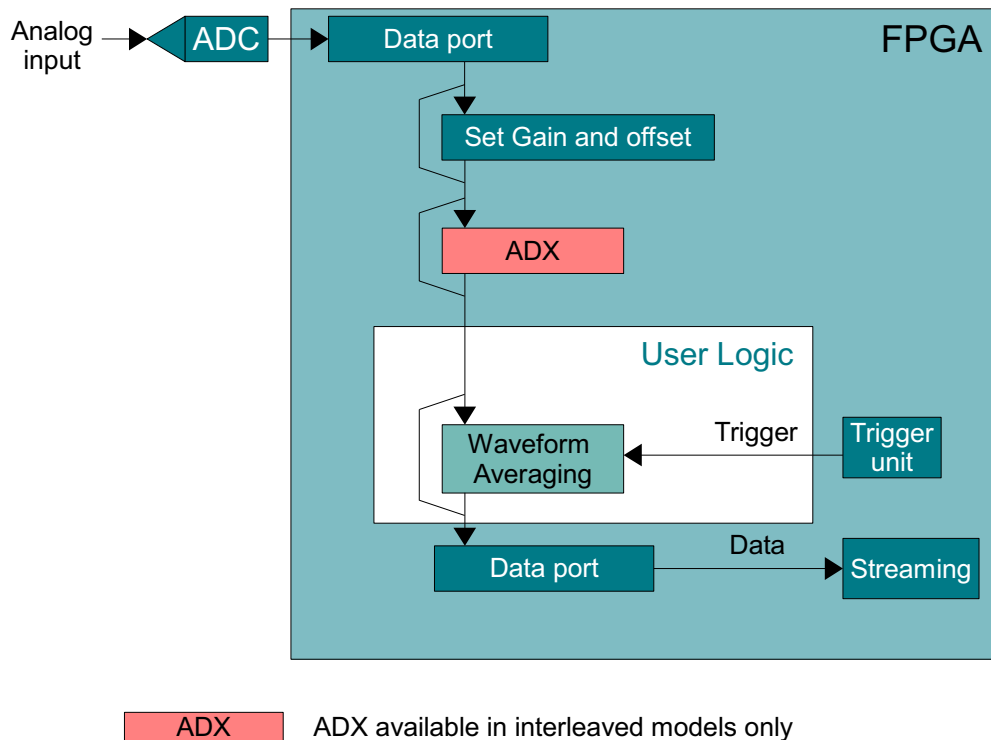

| ADX | ADX available in interleaved models only |

Figure 3: ADQ V6 digitizer family; block diagram placing the WFA

1.5 ADQ Development Kit and WFA

The ADQ Development Kit is a separate tool for designing custom function in the FPGA of the digitizer. The ADQ Development Kit contains necessary digitizer functions and opens an area for custom function. The area is called user logic. The WFA block is placed as a predefined block inside the user logic. This mean that it is possible to interact with custom functions.

ADQ Development Kit is purchased separately.

1.6 Trigger

Waveform Averaging can be used with most of the trigger modes supported by the digitizer. At an accepted trigger, the waveform is accumulated in the accumulation RAM.

1.7 Scheduling modes

There are two scheduling modes in which waveform averaging can operate:

Automatic arm and read mode: After each completed measurement, the content of the accumulator is automatically sent to the host PC over the streaming interface. The waveform averaging unit is automatically rearmed and ready to start the next batch. Automatic arm and read is preferably used in situations when there is little risk of overflowing the output interface. See **Section 2** for more details.

User controlled mode: The user controls the readout of the averaged waveform and re-arms the WFA through software commands. The user controlled mode is often used when focus lies at reading and processing one particular waveform at a time. This also gives the control to the user to schedule the next acquisition. See **Section 3** for more details.

The mode is selected by setting the status flags, **Section 5.3**.

1.8 Readout

The accumulated values can be streamed to the host PC or transfered manually by a user command. The streaming mode means that the host application is ready and waiting for the digitizer to be ready to send data. The real time process of acquisition is then in control. In the manual operation, the host application checks if there is data and transfer it by a command. The host application is then in control. The physical link can be either USB2.0 or PCIe, depending on digitizer form factor.

In streaming mode, host PC has to be prepared to accept data before the WFA is started. The WFA data output is real time scheduled and does not wait for the host to be ready. The accumulator size is 32 bits. Thus the accumulated data is 32 bits per word.

The link out from the WFA[1] [2] to the host interface is a circuit switched fixed rate link but the link to the host PC is packet based. To handle the data reorganization, there is a FIFO in the FPGA#2 of 8kSamples. Set the speed out from the WFA block by the flags in **Section 5.3**. The FAST setting is based on the sample rate from each device. Since the word length is doubled, the number of samples is effectively half but the data rate in Bytes/s is preserved. The settings MEDUIM is a data rate reduction by 10x and SLOW is 100x.

Streaming over USB2.0 requires 512 bytes per packet. This means that the waveform length has to be set in steps of 128 samples (4 bytes per sample).

Streaming over PCIe (in PCIe slot of PC or in cPCIe/PXIe chassis) requires packets in multiples of 128 bytes,. This means that the waveform length is incremented in steps of 32 samples.

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1. For ADQ V5, this is the link between FPGA#1 and FPGA#2, **Figure 2**.
2. For ADQ V6, this is the link from WFA to host interfaces, **Figure 3**

2   Automatic Arm-and-Read mode

2.1   Schedule

In the Automatic Arm-and-Read mode, the schedule in **Figure 4** is used.
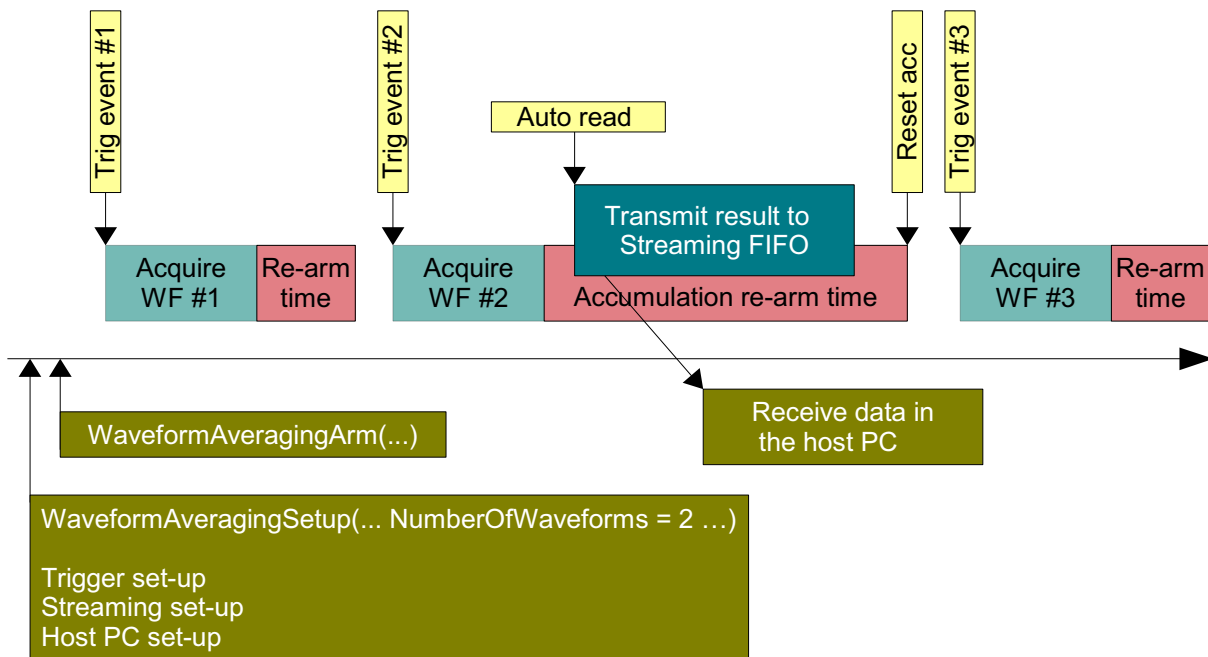

Figure 4: Auto arm and read timing

2.2   Setup

Set up the waveform averaging. In **Figure 4**, an example with accumulation of 2 waveforms is shown. Set the flags according to **Table 3**.

Set up the selected trigger using the trigger control commands[1].

Set up streaming by the SetStreamStatus() command.

Set up the host PC to be ready to receive the data.

2.3   Arm, acquire and re-start

As soon as the arm command has been sent, triggers are accepted. When the requested number of waveforms has been acquired and data is pushed out of the accumulator, the WFA is automatically re-armed and acquisition starts again.

2.4   Read out

The readout is initiated automatically. The readout-time depends on the host PC capacity to receive data. The readout rate can be controlled by flags in the waveform setup.

Select double buffer with the flag for immediate readout.

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1. Note for ADQ V5 only: Level trigger is not allowed in Automatic Arm and Read mode.

Data is pushed out from the accumulator to the streaming FIFO at a fixed rate.If data is not read, the FIFO will overflow and data will be lost. This situation can be detected by the GetStreamOverflow() command.

2.5 Stop

Stopping the transfer has to be done in a controlled way. Otherwise buffers may not be emptied correctly. If this is neglected, restarting the acquisition will result in corrupt data. Procedure to shut down is:

1. Issue a schedule shut down by WaveformAveragingShutdown().

2. Read the last waveform.

3. Wait for the in-idle-state flag. Poll this flag by the WaveforAveragingGetStatus() command.

4. Send the dis-arm command WaveformAveragingDisarm().

3 User controlled mode

3.1 Schedule

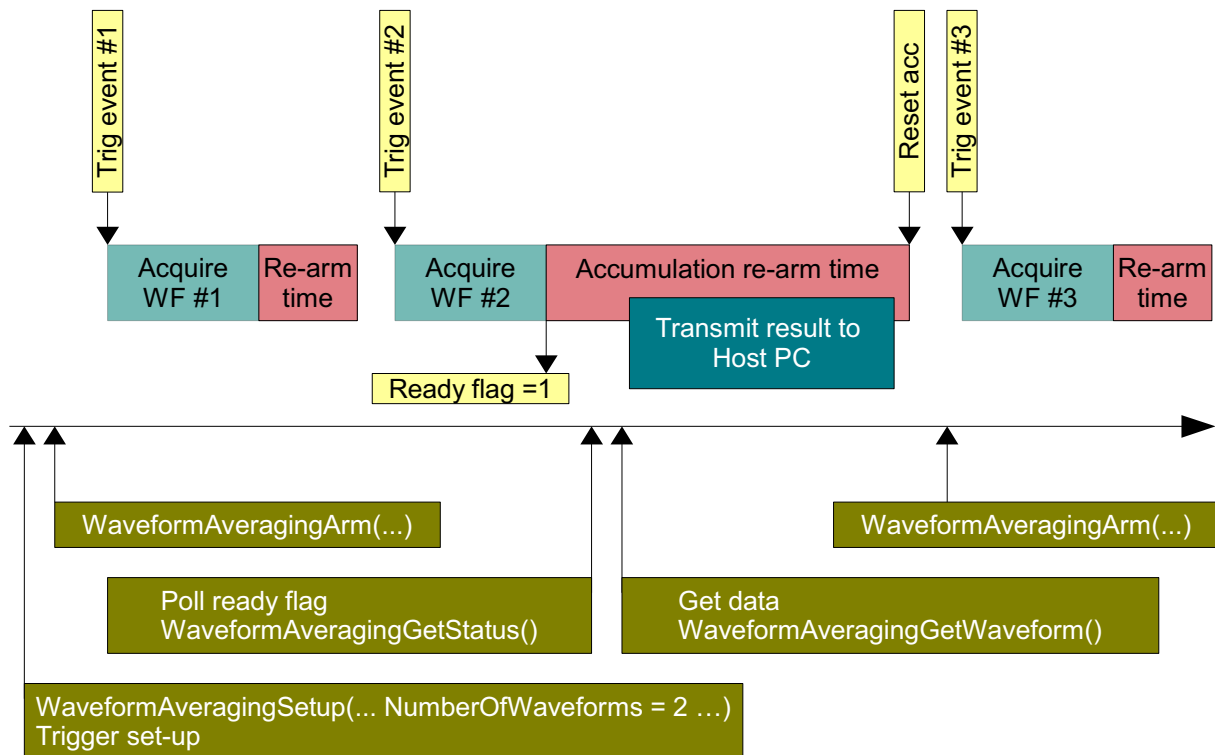In the user controlled mode, the schedule in **Figure 5** is used.

Figure 5: User arm and read timing

3.2 Set up

Set up the selected trigger using the trigger control commands.

Set up the waveform averaging. In **Figure 5**, an example with accumulation of 2 waveforms is shown. Set the flags according to **Table 3**.

3.3   Arm and acquire

As soon as the arm command has been sent, triggers are accepted. When the requested number of waveforms has been acquired, the ready flag is set.

3.4   Read out

Poll the ready flag by the command WaveformAveragingGetStatus() to check that the acqusition is completed. Read out the waveform by the command WaveformAveragingGetWaveform(). After the get waveform command has been sent, the entire accumulator is sent to the PC. Set the read out speed flags to match the data rate of the link to the host PC.

Double buffering (available on some units) is not possible to use in User controlled mode.

3.5   Re-start

The restart is done manually by sending an arm command.

3.6   Using level trigger

When using level trigger, the waveform averaging sets the device in data format 0. Therefore the data format has to be set to 0 when configuring the level trigger.

When reading waveform data, the data format is set to 32 bits by the reading function.

This operations is only required for level trigger. For other trigger options, the data format is maintained the same (32 bits) during the entire operation.

4   Threshold

There is a threshold function before the WFA This is a non-linear operation for suppressing noise. The function operates for both positive and negative pulses.
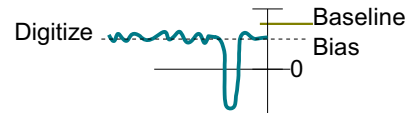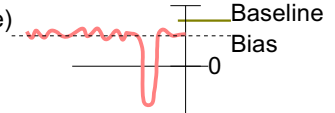
A signal outside a threshold is set to a pre-defined value. Preferably this is the same as the baseline for DBS.
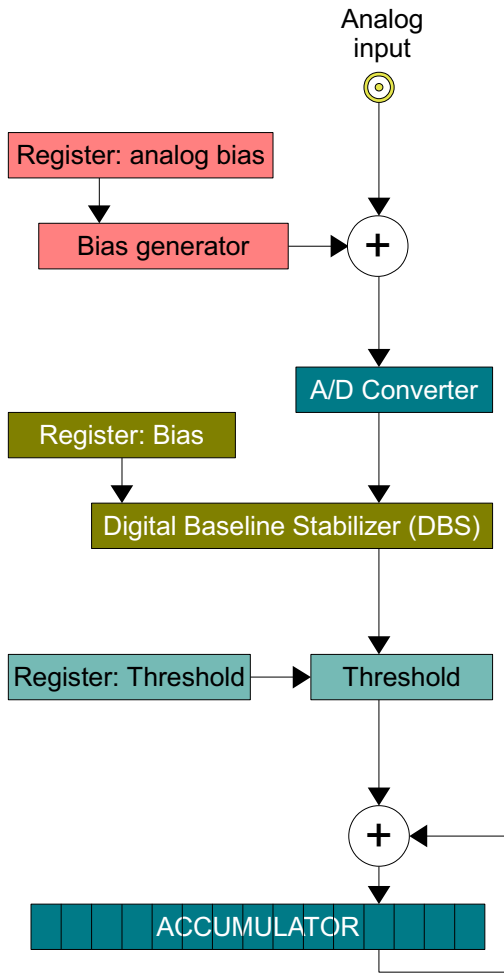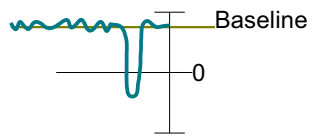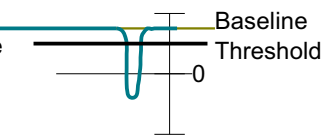
Figure 6: Signal flow

5 Reference guide

5.1 Waveform averaging parameters

MODEL	ADQ114 (ADQ112)	ADQ214 (ADQ212)	ADQ412 4 CH (2 CH)	ADQ1600	ADQ108[1]	UNIT
Waveforms	65535	65535	65535	65535	65535	Waveforms
Waveform length	65536	32768	8192 (16384)	196608	65535	Samples
Input data[2]	16	16	16	16	16	Bits
Output data	32	32	32	32	32	Bits
Pre-trigger length	1920	960	7680	4096	4096	Samples
Trigger delay max	262140	131070	1048560	1048576	1048576	Samples
Pre-trigger and delay Increment	4	2	8 (16)	8	16	Samples
Re-arm time between waveforms	20 (15)	20 (15)	20	45	20	ns
Re-arm time between accumulations	20 (15) ns	min 2 x waveform time	min 2 x waveform time	min 2 x waveform time	min 2 x waveform time	
Trigger[3]	SW/ Ext/ Level/ Int	SW/ Ext/ Level/ Int	SW/ Ext/ Int	SW/ Ext/ Int	SW/ Ext/ Int	
Trigger resolution	Sample	Sample	Sample	Sample	Sample	
Double buffer	YES	NO	NO	NO	NO	

Table 1: ADQ WFA parameters.

1. Availability of WFA TBC
2. Input data is always MSB aligned 16 bit format regardless of the resolution of the digitizer.
3. Level Trigger Mode is not allowed in Automatic arm-and-read mode. To use level trigger, data format must be switched between averaging phase and readout phase.

5.2 Waveform averaging API commands

API COMMAND	DESCRIPTION
WaveformAveragingSetup	Set up the waveform averaging
WaveformAveragingArm	Start to accept triggers
WaveformAveragingDisarm	Stop accepting triggers
WaveformAveragingStartReadout	Start reading data
WaveformAveragingGetWaveform	Read out the accumulated record
WaveformAveragingGetStatus	Check status of Waveform averaging
WaveformAveragingShutdown	Shut down automatic arm and read mode.

Table 2: List of WFA commands. See ADQ API user's guide for a complete list

5.3 Waveform averaging status flags

FLAG NAME	DESCRIPTION	BIT	USER CONTROL	AUTO ARM AND READ
COMPENSATE_EXT_TRIG	Compensate for external trigger latency	0x0001	1 for external trig 0 else	1 for external trig 0 else
COMPENSATE_LEVEL_TRIG	Compensate for level trigger latency	0x0002	1 for level trig 0 else	0
READOUT_FAST	Streaming read-out speed from accumulator to FIFO	0x0004	System dependent. Select slow for USB.	System dependent. Select slow for USB.
READOUT_MEDIUM		0x0008		
READOUT_SLOW		0x0010		
ENABLE_LEVEL_TRIGGER	Enable level trigger (ADQ V5 only)	0x0020	1 for level trig	0
ENABLE_GET_WAVEFORM	Enable read-out of waveforms	0x0040	1	0
ENABLE_AUTOARMNREAD	Enable auto arm and read mode	0x0080	0	1
READOUT_A_ONLY	Select channel A only	0x0100	User's choice	User's choice
READOUT_B_ONLY	Select channel B only	0x0200	User's choice	User's choice
IMMEDIATE_READOUT[1]	Select double buffer	0x0400	0	User's choice

Table 3:   List of WFA flags. See ADQ API user's guide for a comprehensive description.

1. Available on some models only.

5.4 Waveform sample order ADQ V5

There are several ADC configurations that can be connected to the waveform averaging block resulting in different operational modes. The result is that the real sample order is different in different configurations, **Table 4**. The output signals from the ADQ V5 digitizer family output has to be re-ordered. waveform samples in the order (Channel A & B)

MODEL	SAMPLE ORDER	MODE
ADQ214 / ADQ212	A0 A1 A2 A3 A4 A5 A6 A7	Readout A only
ADQ214 / ADQ212	B0 B1 B2 B3 B4 B5 B6 B7	Readout B only
ADQ214 / ADQ212	A0 A1 B0 B1 A2 A3 B2 B3	Readout 2 channels
ADQ114 / ADQ112	A0 A2 A1 A3 A4 A6 A5 A7	All modes

Table 4:   ADQ V5 digitizer family output sample order.

In user controlled mode, the sort operation is included in the WaveformAveragingGetWaveform().

5.5 Waveform sample order ADQ V6

For ADQ1600 with only one channel, there is no need to reorder the data.

For ADQ412, see ADQ waveform averaging example script on how to re-order data in 2 and 4 channel mode.

In user controlled mode, the sort operation is included in the WaveformAveragingGetWaveform().

6 Example software

6.1 C/C++ example

There is an example code in the Software Development Kit: ADQAPI_WaveformAveraging.

6.2 MATLAB Example Code

From MATLAB, only user controlled mode is available. (Streaming is not possible when using MATLAB.) There is an example file in the Software Development Kit: ADQ_waveform_averaging_example.m. The example contains several trigger modes. To illustrate external trigger and level trigger, the trigger output function is used as signal source. Connect the trigger signal to channel A through a 10 dB attenuator, **Figure 7**. Open the example and edit the code to select different triggers.
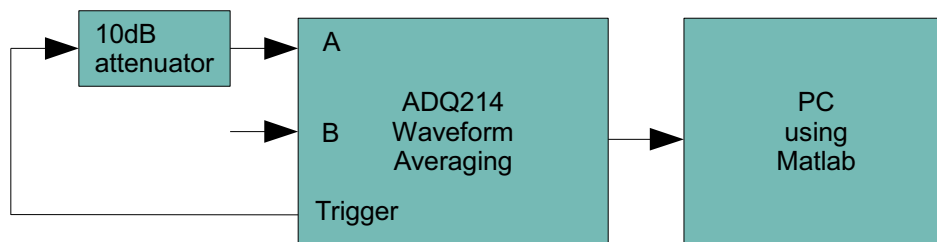

Figure 7: Set up for MATLAB example code

7 Measurement examples
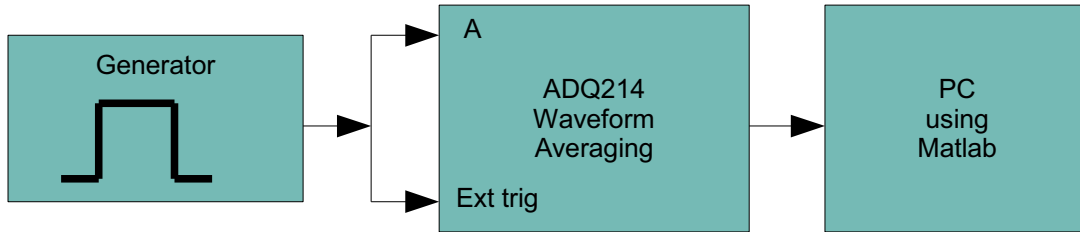
7.1 Square wave generator

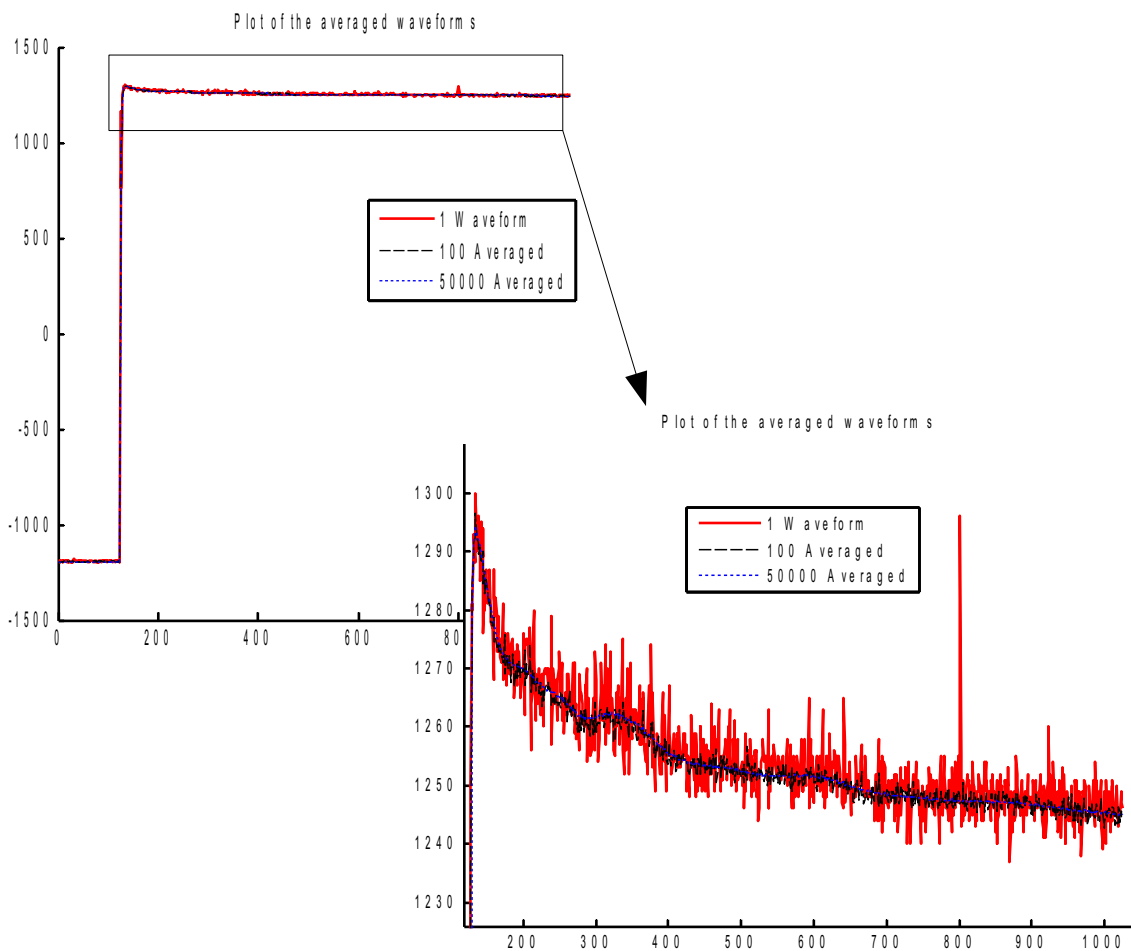**Figure 8: Square wave generator set up**

Figure 9: Square wave measurement

7.2 Sine wave generator (low-cost)

This experiment is made with a noisy sine wave generator in order to get illustrative results.
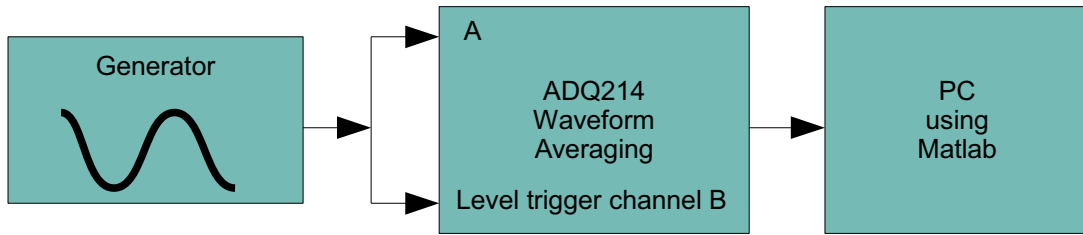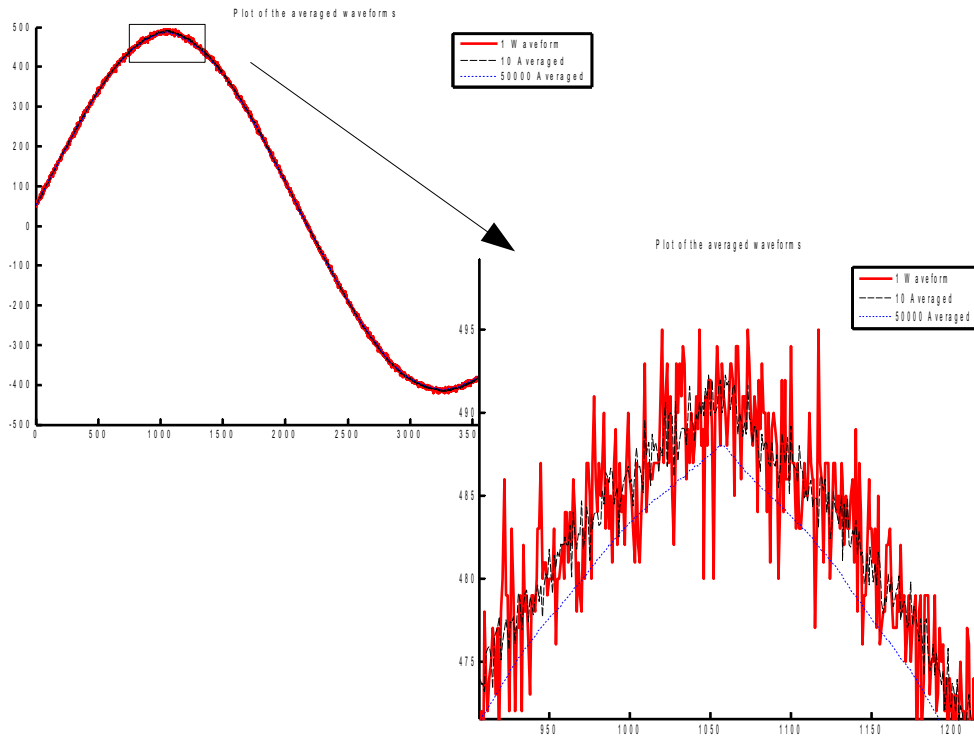
Figure 10: Sine wave generator set up

Figure 11: Sine wave measurement

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