

# Operating Electronics for Spectral Sensors and Detector Arrays

## Readout Operating Modes for Spectral Sensors

### Technical Note

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## Revision History

Version 1.50 Released base version

Version 1.60 First revision March 2003

Version 1.61 Operating mode Burst not supported by MOE-C161

Version 1.73 Completely revised based on several revisions of German version:

# 1 Introduction

This document explains the operating modes for spectral data acquisition implemented in tec5 Operating Electronics and drivers.

The individual operating modes are each designed and optimized for specific types of data acquisition.

The modes of operation can be classified into three main groups:

1. Software-controlled synchronous data acquisition
2. Software-controlled asynchronous data acquisition (buffered)
3. Externally triggered data acquisition

The following operating modes are assigned to the main classes:

1. Software-controlled synchronous data acquisition
  - StartNewScanWithoutCleaning
  - StartNewScanWithCleaning
  - SyncToContScan
2. Software-controlled asynchronous data acquisition (buffered)
  - GetLastScan
  - GetBufferedScan
3. Externally triggered data acquisition
  - ExternalTriggerSlope
  - ExternalTriggerPulse

Each tec5 Operating Electronics has been designed for the purpose of operating photodiode-array based Spectral Sensors and photodiode arrays. The modes of operation are implemented in hardware and firmware in their essential parts. Once started, they run autonomously without imposing real time requirements on the PC and the operating system. The drivers set the parameters for the operating modes, start data acquisition and read the acquired data from the interface electronics. Using interrupt-controlled processes and data buffering, the operating system is relieved from any real-time requirements.

Due to the individual properties of the different tec5 Operating Electronics, not each operating mode is supported by all types of electronics (see below). The support mainly depends on the hardware (or firmware version of CPLD and  $\mu$ -controller), the driver implementation, as well as the function library SDACQ32MP.

## 1.1 Definition of Terms

Within this documents several specific terms are used:

<b>Integration time:</b>	time period during which the sensor is collecting light and creating electronic signals, exposure time
<b>Readout time:</b>	time used to read the information from the array. Depending on the type of sensor this can happen within the integration time period (valid for all Si PDAs, not valid e.g. for InGaAs arrays, see next section for details).
<b>Scan:</b>	readout (scan) process of spectral sensor
<b>Readout:</b>	readout (scan) process of spectral sensor
<b>Dummy scan:</b>	sensor readout (and deleting accumulated photoelectrons = clearing) of spectral sensor <u>without</u> saving the (spectral) information
<b>Data scan:</b>	sensor readout (and deleting of accumulated photoelectrons = clearing) of spectral sensor <u>with</u> saving the (spectral) information, a data scan generates a spectral data set (spectrum)
<b>Measurement cycle:</b>	sequence of one dummy scan followed by a series of n data scans with the preset integration time
<b>Single scan:</b>	measurement cycle consisting of one dummy scan and a data scan with the preset integration time, then transfer of the acquired data set to the application software
<b>Averaging:</b>	measurement cycle consisting of one dummy scan and n data scans with the preset integration time, the data sets are averaged at driver level, the averaged (single) data set is transferred to the application software ( $1 \leq n \leq 100$ )
<b>Burst:</b>	measurement cycle consisting of one dummy scan and n data scans with the preset integration time, the data of each scan is transferred to the application software ( $1 \leq n \leq 30,000$ )
<b>Driver:</b>	extension of operating system for use of interface electronics with various PC bus interfaces (PCI, USB, ISA, PC/104). The driver manages hardware access, cycling of the individual operating modes and the complete data acquisition process.
<b>Function library:</b>	DLL (SDACQ32MP.DLL) providing the interface to the user program on the application level. The function library controls the different interfaces and features of the individual Operating Electronics under the various Windows 32 bit operating systems.

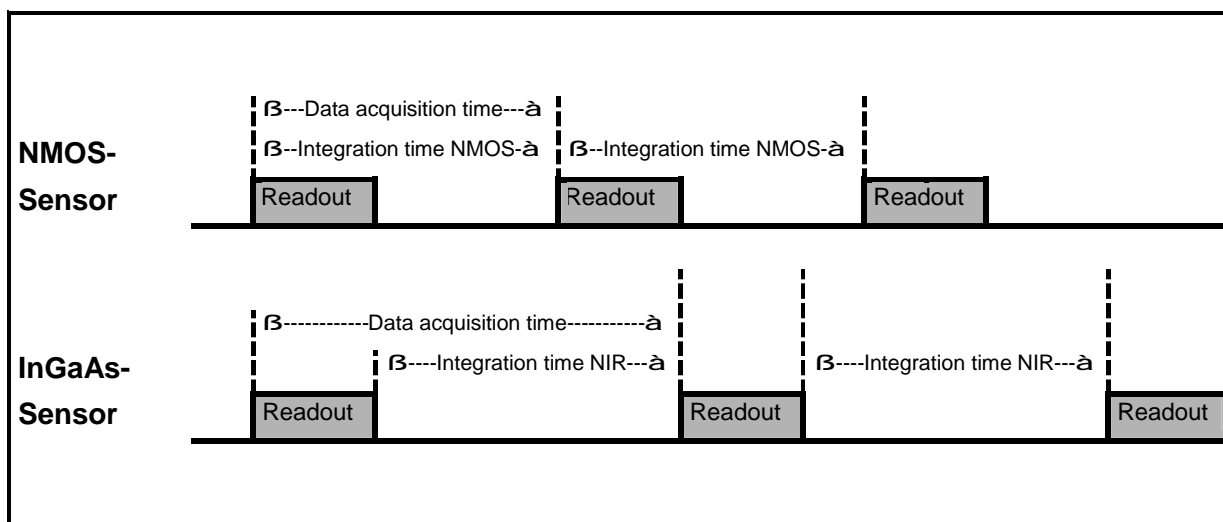
## 1.2 Special Behavior of InGaAs Arrays

The following sections of this document contain detailed analyses of the timing behavior for spectral data acquisition in various operating modes, assuming that the readout time for the sensors is part of the integration time (exposure time). This is true for Si-PDAs and CCD-sensors, which are generally light sensitive during readout.

In case of NIR InGaAs Arrays, the exposure and readout phases are separated, i.e. charges accumulated are frozen during the readout process. If the operating electronics would not take this behavior into account, the effective exposure time would be reduced by the time required for readout. tec5 Operating Electronics compensate for this effect by internally prolonging the data acquisition cycle by the (constant) duration of readout for the sensor. In this way it is assured that the preset value for the integration time is the effective exposure time also when NIR sensors are used. As an inevitable consequence, this method reduces the maximum measurement rate.

### Note:

In multichannel applications using sensors of different technologies, this technique may lead to inter-channel time shifts although equal integration time is programmed.



## 1.3 Notes about the Timing Diagrams

### Retrieved Data

In the timing diagrams, the phase „retrieved data“ marks the time segment between the start of a scan (analog-to-digital conversion of the first pixel) and the instant when data are ready for being taken over by the Application software.

- 1) For electronics with PC bus interface (PCI / PC-104), the following sequence is applied:
  - During the data scan, spectral data are first buffered in a FIFO memory on the interface board
  - At the end of a data scan the electronics issues an interrupt, signalling to the PC that a complete spectral data set is available in the buffer.
  - The driver's interrupt service routine reads the spectral data after completion of the scan and prepares it for retrieval by the application software.
  
- 2) For interface electronics with serial bus connection (USB):
  - Parts (pixels) of the spectral data set are organized into USB data packages of 64 bytes (USB 1.1 full speed) or 512 bytes (USB 2.0 high-speed) and prepared for transfer during the readout scan.
  - While the scan is running, the PC polls the status of available data packages and retrieves them over the USB.

Thus, the instant for spectral data transfer to the application software always happens after the completion of the data scan. The delay depends on the performance and workload of the PC and, in some cases, on the bandwidth of the serial bus connection.

## 2 Software-Controlled Synchronous Data Acquisition

### 2.1 General

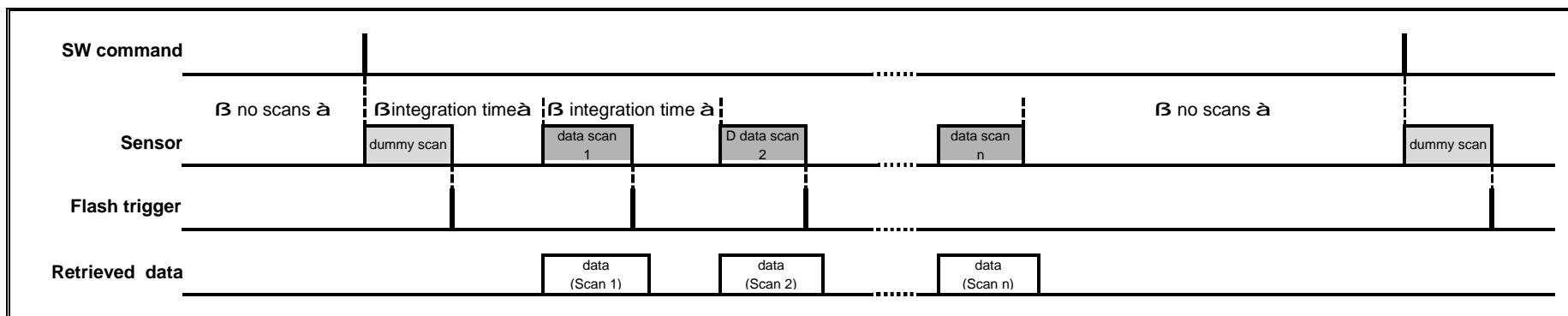
The class of software-controlled synchronous data acquisition comprises all operating modes which start a measurement cycle by a software command from the application software. This guarantees that all acquired spectral data are really requested by the application and, therefore, an unambiguous time relation is given.

## 2.2 StartNewScanWithoutCleaning

The operating mode StartNewScanWithoutCleaning provides a simple measurement cycle consisting of a dummy scan and n data scans. The measurement cycle is started by a command from the application software. At first, a dummy scan is performed to clear the accumulated photoelectrons within the sensor. Then, a series of data scans with the preset integration time is executed. The measurement cycle is stopped by the driver as soon as all required data scans are completed.

Operating Mode Support		
Single scan, averaging, burst		
Operating Electronics	Driver (NT4.0 and WDM)	Function Library SDACQ32MP
PD-ISA16V3	≥ version 2.0.0.0	≥ version 1.6.0.0
PD-PCI01V1	≥ version 1.0.0.0	≥ version 1.6.0.0
PD-10401V1	≥ version 1.0.0.0	≥ version 1.6.0.0
PD-USB01V1	≥ version 1.0.0.0	≥ version 1.6.0.0
MOE-C161	≥ firmware 3.00	≥ version 1.6.0.0

### Example: Burst or averaging over n data scans



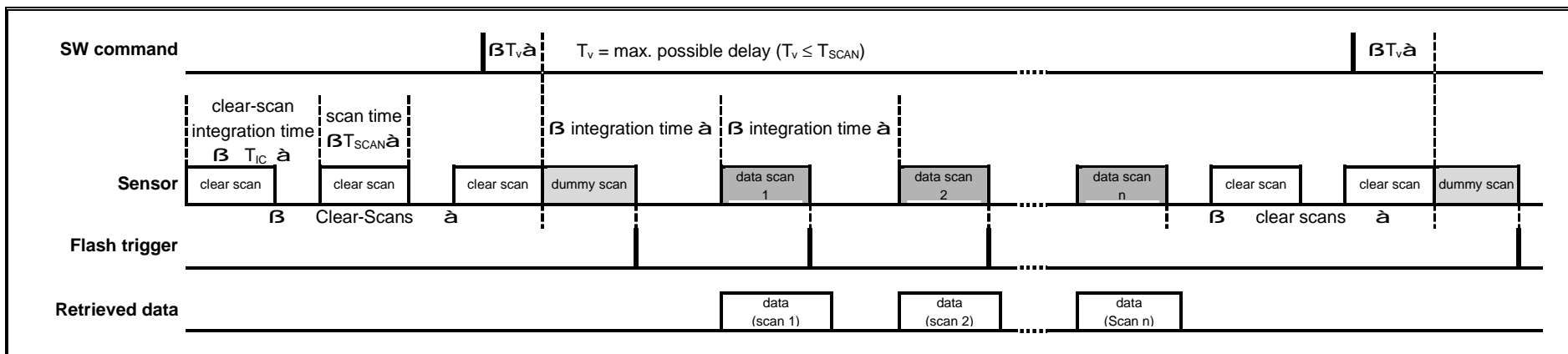
### 2.3 StartNewScanWithCleaning

The operating mode StartNewScanWithCleaning is an expansion of the mode StartNewScanWithoutCleaning. The start of the measurement cycle as well as the data acquisition is realized in a similar way. Since the sensor is not read out between two commands StartNewScanWithoutCleaning, the Spectral Sensor may get saturated, degrading the accuracy of subsequent data scans. To avoid this saturation effect, StartNewScanWithCleaning puts the sensor in a mode of continuous readout after the measurement cycle is performed. The integration time for cleaning can be set independently. This readout mode performs a recurrent reset of the Spectral Sensor, so that saturation is avoided.

Operating Mode Support		
Single scan, averaging, burst		
Operating Electronics	Driver (NT4.0 and WDM)	Function library SDACQ32MP
PD-ISA16V3	≥ version 2.0.0.0	≥ version 1.6.0.0
PD-PCI01V1	≥ version 1.0.0.0	≥ version 1.6.0.0
PD-10401V1	≥ version 1.0.0.0	≥ version 1.6.0.0
PD-USB01V1	≥ version 1.0.0.0	≥ version 1.6.0.0
MOE-C161	≥ firmware 3.00	≥ version 1.6.0.0

After the software request, the continuous cleaning readout mode is stopped synchronously first. Since an active scan of the detector array will not be interrupted, the start of the new measurement cycle can be delayed. At maximum, this delay can be as long as the required readout time for the Spectral Sensor (e.g. MMS with 256 pixels and FEE-HS = 1.5ms).

#### Example: Burst or averaging over n data scans



## 2.4 SyncToContScan

The operating mode SyncToContScan allows to use a special continuous readout mode. The Spectral Sensor is read out repeatedly at the selected (measurement) integration time, all data are discarded. When spectral data acquisition is requested by software, the readout is synchronized to the next readout scan and the data of the next  $n$  scans are transferred to memory.

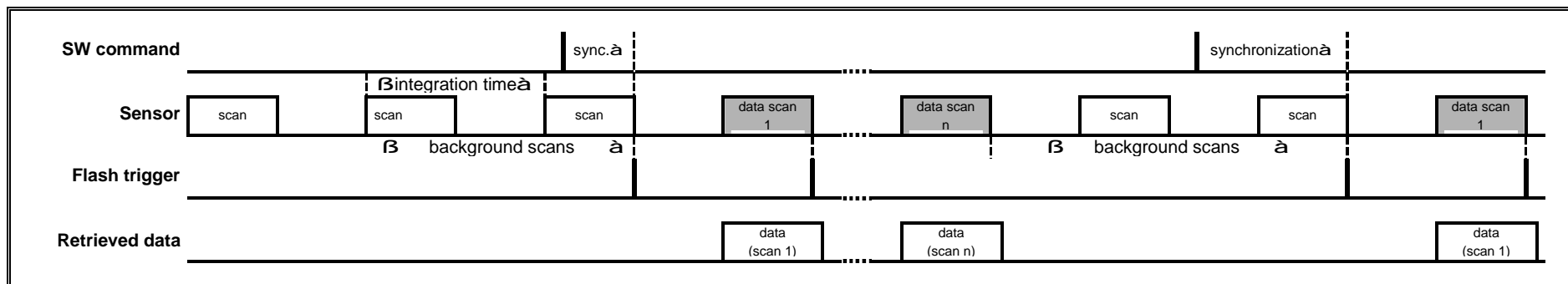
Due to the stochastic course of events in hardware and software, the software request for spectral data is generally asynchronous to the continuous readout process of the sensor. For this reason, a delay of up to one integration time between command sent and start of the measurement can arise.

The active measurement cycle is not interrupted, the Spectral Sensor is operated in fully periodic cycles with respect to integration time and the time between two readout events.

Operating Mode Support		
Single scan, averaging, burst		
Operating Electronics	Driver (NT4.0 and WDM)	Function library SDACQ32MP
PD-ISA16V3	≥ version 2.0.0.0	≥ version 1.6.0.0
PD-PCI01V1	≥ version 1.0.0.0	≥ version 1.6.0.0
PD-10401V1	≥ version 1.0.0.0	≥ version 1.6.0.0
PD-USB01V1	≥ version 1.0.0.0	≥ version 1.6.0.0
MOE-C161	≥ firmware 3.15	≥ version 1.6.0.0

This operating mode is especially useful for sensors which are sensitive to integration time changes, requiring several cycles to provide a stable measurement signal (e.g. NIR InGAs-sensors).

### Example: Burst or averaging over $n$ data scans



## 3 Software-Controlled Asynchronous Data Acquisition (Buffered)

### 3.1 General

This group of data acquisition modes comprises all operating modes in which the driver acquires one or several data scans, independent from requests by the application program, and saves the data to an internal ring buffer (software buffer). In these modes, the measurement cycle is not started by a data request (software command). The application software reads spectral data sets from the buffer which were acquired earlier. If no spectrum is available in the internal buffer at the time of request, the driver waits for the next data scan.

These operating modes do not assure that spectral data are acquired after the request by the application program. Actually, no accurate timing relation is available. The application software has to

assure that acquired spectra are taken over from the driver in time, otherwise the driver returns a warning.

The continuous recording of data scans causes high or very high CPU processing load, especially at short integration times. In some extreme cases, this can lead to operating the CPU under full load only transferring and buffering data. Therefore, this mode should not be used over a longer period at short integration times. It should be considered to change to a synchronous data acquisition mode temporarily.

### 3.2 GetLastScan

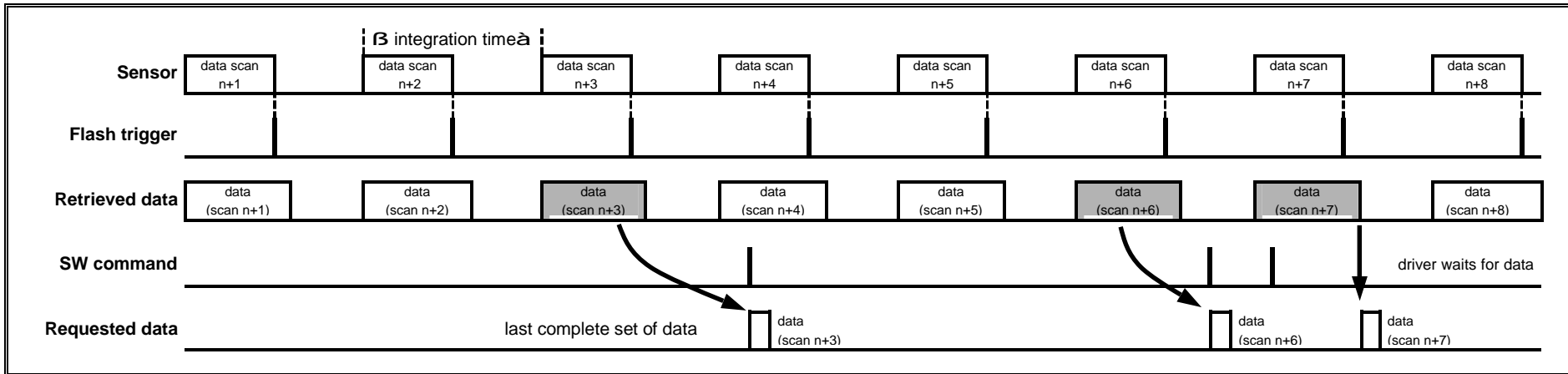
The operating mode GetLastScan allows the driver to access and transfer the last acquired spectrum (single or averaged) at any time. The driver continuously saves the data of the last scan to an internal intermediate buffer, independent from and asynchronous to potential software requests. This data set can be accessed by the application software at any time. In case the current spectrum has been already transferred to the application program, the driver waits for the next data scan (exception: MOE-C161: this unit always transfers the last data set, even if it has been transferred before).

This operating mode allows consistent / gapless acquisition and processing of continuously acquired data sets. However, the appli-

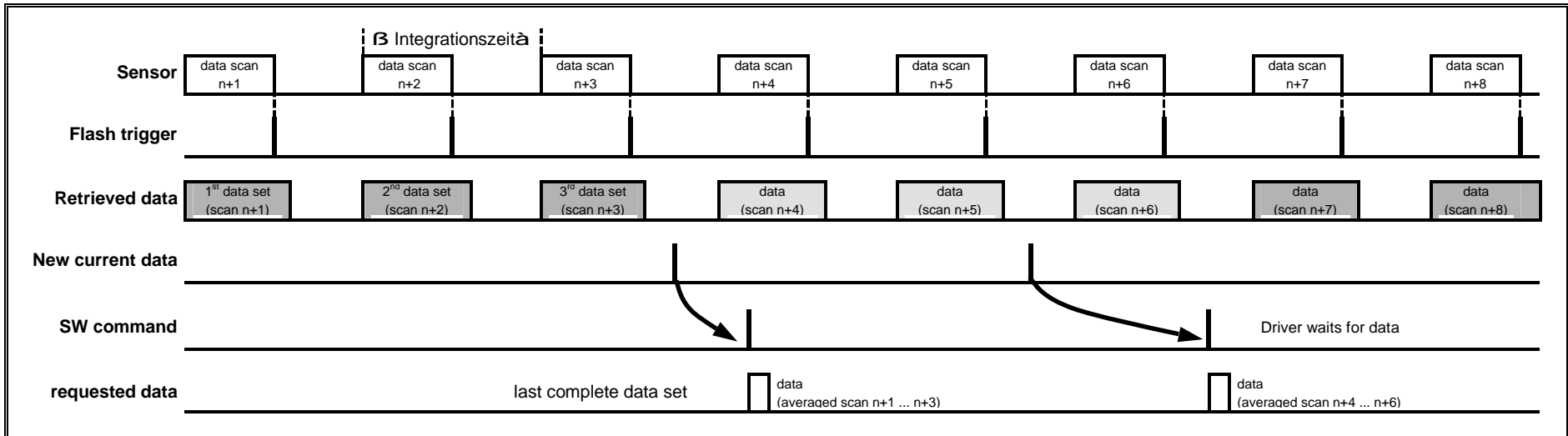
Operating Mode Support		
Single scan, averaging, burst		
Operating Electronics	Driver (NT4.0 and WDM)	Function library SDACQ32MP
PD-ISA16V3	not supported	not supported
PD-PCI01V1	≥ version 1.1.0.0	≥ version 1.6.4.0
PD-10401V1	≥ version 1.0.0.6	≥ version 1.6.4.6
PD-USB01V1	≥ version 1.0.0.0	≥ version 1.6.4.6
MOE-C161	≥ firmware 3.00	≥ version 1.6.0.0

cation software has to assure that the data are retrieved keeping pace with the the integration time intervals. If this is not possible due to short integration times or specific properties of the operating system in use, the mode GetBufferedScan should be used.

#### Example: Single scan

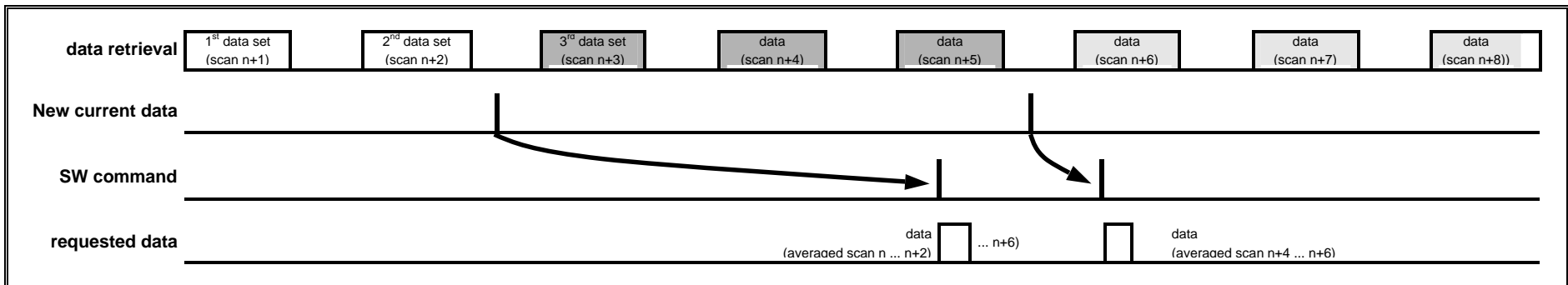


**Example 2: Averaging of three Data Scans**



Remark:

Depending on phasing of the software request w.r.t. the fixed acquisition pattern of n averaged spectra, a period of up to n integration times may pass from the last spectrum acquired for the current averaged data and the software request!



### 3.3 GetBufferedScan

Using a ring buffer within the driver, the operating mode Get-BufferedScan allows asynchronous and consistent / gapless acquisition and buffering of spectral data sets.

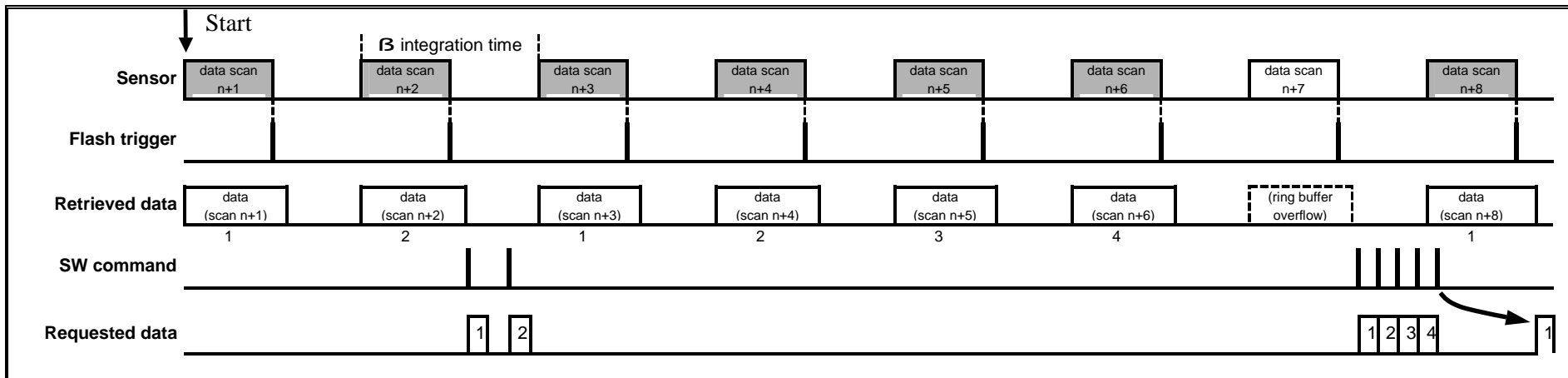
Buffer Capacity [Number of data scans]	
Max. 32767	Limited by driver software
Max. 256	Limited by function library SQACQ32MP (if used)
12	Default-buffer capacity

The driver saves the preset number of gapless data sets to its internal ring buffer, independent from and asynchronous to potential software requests. The buffered data can be retrieved by the application at any time. If no spectrum is available for transfer to the application program, the driver waits for the next data scan.

Operating Mode Support		
Single scan, averaging, burst		
Operating Electronics	Driver (NT4.0 and WDM)	Function library SDACQ32MP
PD-ISA16V3	not supported	not supported
PD-PCI01V1	≥ version 1.1.0.0	≥ version 1.6.4.0
PD-10401V1	≥ version 1.1.0.6	≥ version 1.6.4.6
PD-USB01V1	≥ version 1.1.0.0	≥ version 1.6.4.6
MOE-C161	not supported	not supported

This operating mode consistently buffers the preset number of data sets. If a data set is requested by the application program, the driver also returns the number of data sets acquired to the buffer so far. In case the application software does not retrieve the data in time and there is a buffer overflow, the driver returns a warning. In addition, the application program can retrieve the number of lost data sets.

#### Example: Ring buffer depth 4 scans



## 4 Externally Triggered Data Acquisition

### 4.1 General

The group of externally triggered data acquisition modes comprises all modes of operation, in which a measurement cycle is activated by an external trigger event.

After a request by the application program, the Operating Electronics is prepared for an externally triggered measurement cycle and put in a wait condition. The trigger event starts the measurement cycle consisting of a dummy scan and  $n$  data scans. The delay  $t_D$  between the trigger event and the start of the measurement cycle depends on the hardware configuration and is typically shorter than  $120 \mu\text{s}$ .

A pulse (rising edge) or any slope (rising or falling edge) of a TTL signal applied to the “ExternalScanTriggerInput” pin of the interface electronics may be selected as triggering event by using the corresponding operating mode.

A programmable timeout is available for supervision of the routine. If the timeout period elapses without a trigger event detected, the routine is interrupted and an error message is returned.

## 4.2 ExternalTriggerSlope & ExternalTriggerPulse

The operating modes ExternalTriggerSlope and ExternalTriggerPulse allow measurement cycles consisting of a dummy scan and n data scans to be started by an external trigger signal. The measurement cycle is prepared by a software command and started by a trigger event. Depending on the selected operating mode, the trigger event starting the measurement can be a pulse (positive slope) or any change in slope. At first, a dummy scan is performed to clear the accumulated photoelectrons within the sensor. Then, a series of data scans with the preset integration time is executed. The measurement cycle is stopped by the driver as soon as all required data scans are completed.

Operating Mode Support		
Single scan, averaging, burst		
Operating Electronics	Driver (NT4.0 and WDM)	Function library SDACQ32MP
PD-ISA16V3	≥ version 2.0.0.0	≥ version 1.6.0.0
PD-PCI01V1	≥ version 1.0.0.0	≥ version 1.6.0.0
PD-10401V1	≥ version 1.0.0.0	≥ version 1.6.0.0
PD-USB01V1	≥ version 1.0.0.0	≥ version 1.6.0.0
MOE-C161	≥ firmware 3.00	≥ version 1.6.0.0

### Example: Averaging or burst over n scans, pulse triggered

