



NV04ASC-HW Asynchronous photon-driven camera

User manual

Version 0.2

Contents

1	Software and drivers	3
2	First power on	3
3	Output data	3
4	Asynchronous operation	4
5	Saturation	5
6	Operating the camera using the NovoViz software	7
6.1	Live stream and image capture	7
6.2	Clock configuration	9
6.3	Pixel masking	10
6.4	AUX port	11
6.5	Saving current configuration	12
6.6	Operating multiple cameras	12
7	Operating the camera using external scripts	13
7.1	Configuration, version and ID commands	13
7.2	Pixel masking commands	14
7.3	Exposure commands	15
7.4	Miscellaneous commands	16

1 Software and drivers

The NV04ASC-HW Asynchronous photon-driven camera requires the installation of FTDI drivers in order to operate. Additionally, it is recommended, but not mandatory, to install the NovoViz Camera software which provides a plug & play experience with the camera. The list is summarised in the following table:

	Version
FTDI driver	D3XX
NovoViz Camera Software	Win64

2 First power on

The NV04ASC-HW Asynchronous photon-driven camera uses the USB-C interface for both power and data. After installing the drivers and the software, connect the camera to the PC and launch the NovoViz Camera software or your custom script. At this point, the camera is ready and no further setup steps are necessary. By default, there will be no output from the camera.

3 Output data

The camera output data consists of events, each corresponding to a photon detection on the pixel array. The number of output events, and thus the output bandwidth, is dependent on the photon flux and reaches zero when no photons are detected. Each output event consists of the pixel column index X, row index Y and photon arrival timestamp T . An additional flag bit F is used to mark a time interval equal to the exposure duration set by the user, which allows easy binary frame accumulation. Figure 1 shows the bit allocation of the 24 bits of the output event.

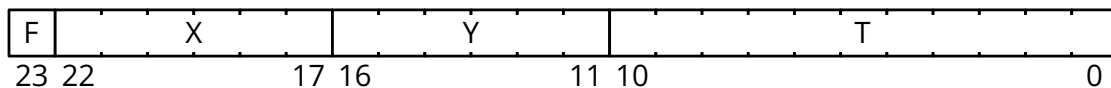


Figure 1: Camera output format.

Timestamp T is generated on-chip and is continuously incremented with a frequency of f_{CLK} and each photon hit is assigned the current T value, even in simultaneous detection cases. When the maximum value of 2047 is reached, the next clock cycle will reset the timestamp to zero. Analysing the event data over longer time intervals requires the user to keep track of timestamp overflows.

The flag bit F is generated off-chip, by the camera hardware, and is appended to the event information generated by the NV04ASC sensor. For very short exposure times, the discrepancy due to the non-chronological asynchronous operation of the sensor can have a significant influence on the processing of

the output data.

4 Asynchronous operation

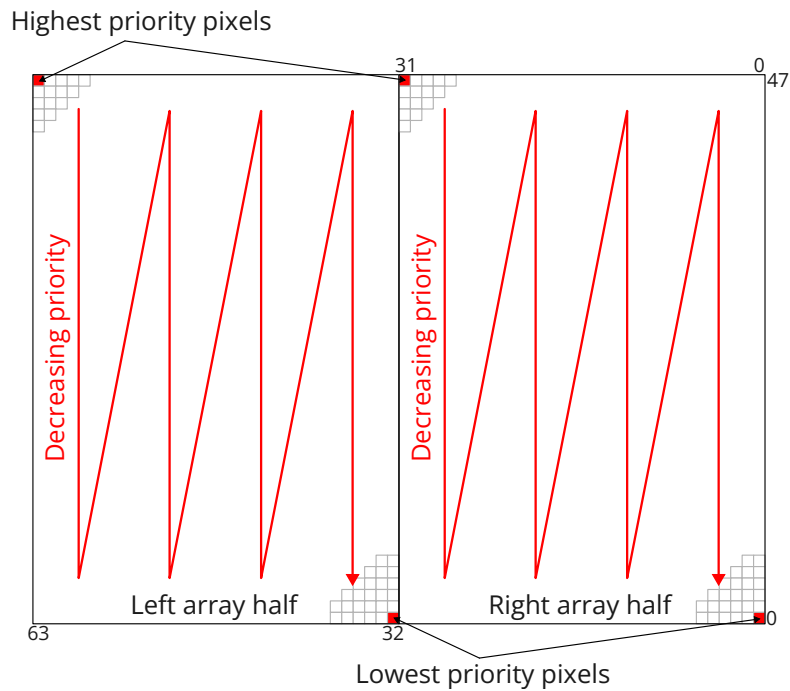


Figure 2: Pixel priority map used by the arbiter circuit when servicing the pixel events.

Photon detection events across the pixel array are processed according to pixel priority i.e. an output event is generated for a specific pixel if and only if there are no photon events in pixels of higher priority. The pixel priority map is shown in Figure 2.

The arbiter circuit evaluates new pixel requests at a frequency of f_{CLK} . The priority-based approach results in an output event stream that does not follow photon arrival chronology, because a photon hit on a higher priority pixel will be serviced first even though older requests are present. As a consequence, the pixel dead time is dependent on photon activity. Figure 3 represents a toy model showing the reordering of photon arrivals in the output stream.

It is important to note that the output event order is irrelevant, because the photon arrival time in each event can be used to arrange the photon events in chronological order.

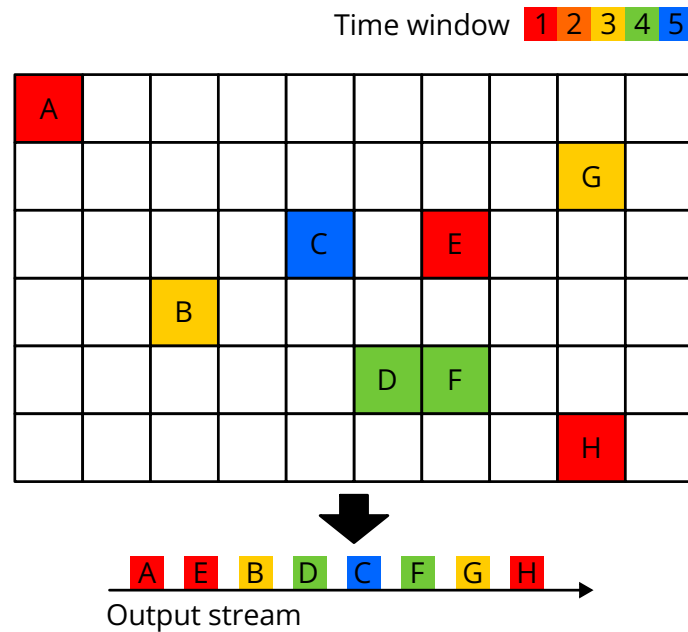


Figure 3: Toy model showing the effect of the priority-based pixel readout on the order of the output events.

5 Saturation

The NV04ASC-HW Asynchronous photon-driven camera is designed to operate in low light conditions. If the number of photon events exceeds the E_G limit specified in the datasheet, the sensor will automatically narrow the region of interest (ROI) by ignoring low priority pixels. This will result in a recognizable pattern, as shown in Figure 4. The effect can be mitigated by masking the hot pixels in the array and by using neutral density filters in the optical path.



The sensor operates as two independent halves which means the saturation effect can be different for the two sides of the image and masking pixels in one will not influence the saturation limit in the other.

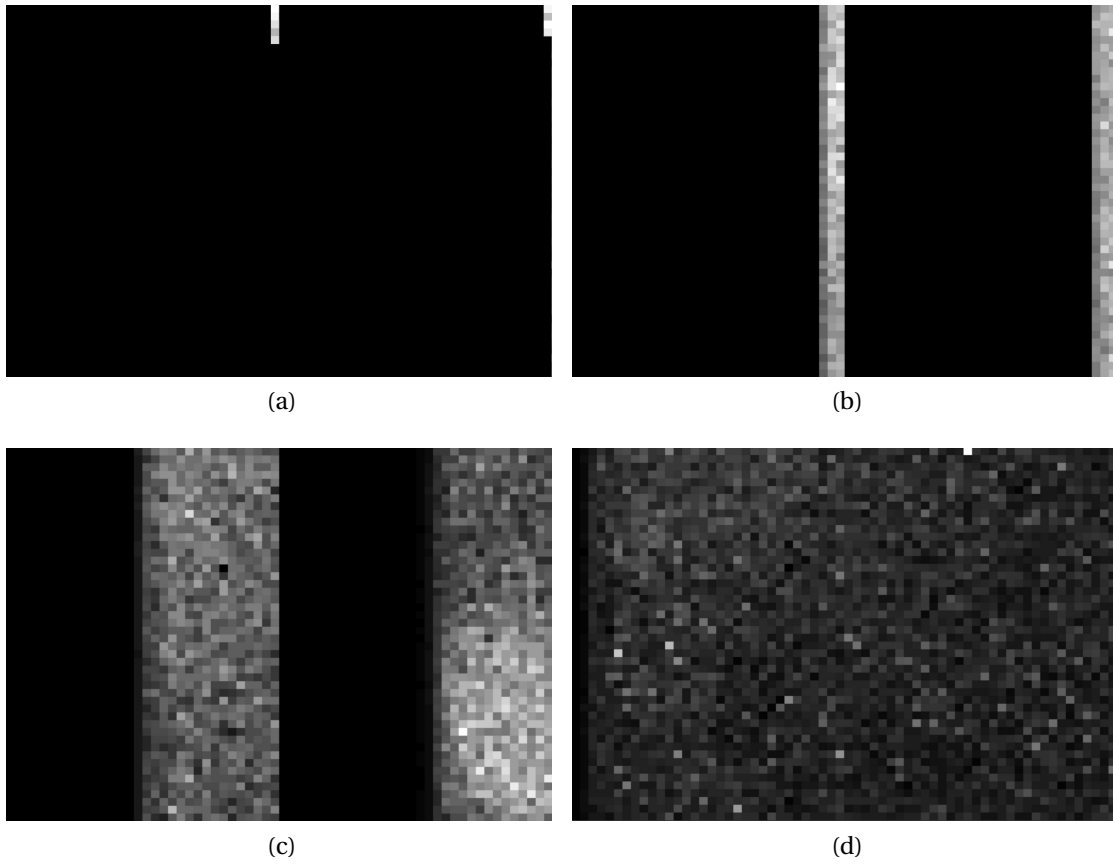


Figure 4: Sensor outputs for different levels of saturation: (a) extreme, (b) severe, (c) medium and (d) minor.

6 Operating the camera using the NovoViz software

6.1 Live stream and image capture

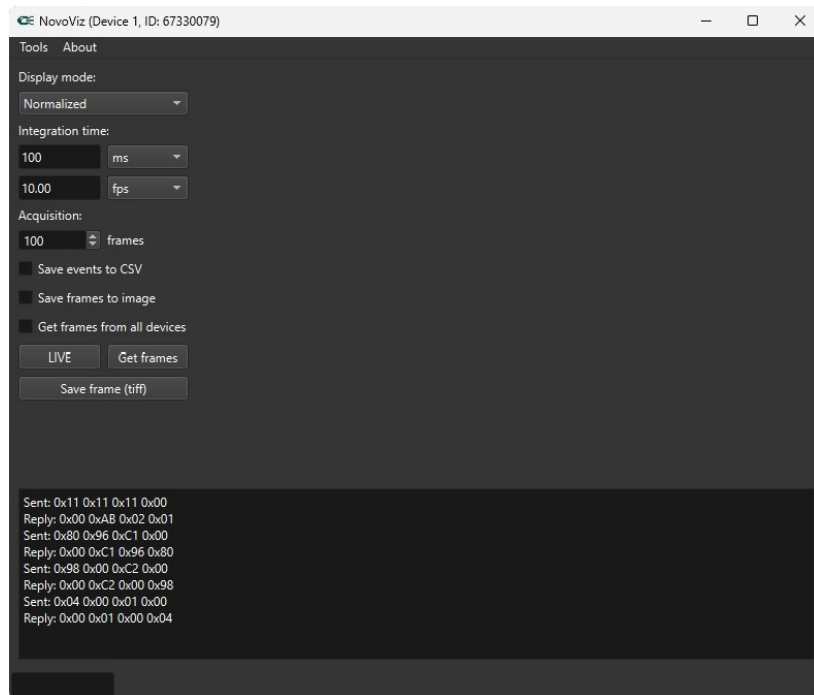


Figure 5: Default starting state of the NovoViz Camera Software

The default starting state of the NovoViz Camera Software is shown in Figure 5. The interface offers direct access to all the functionalities required to set the frame integration time and the display mode as well as to capture images and get a live view of the output stream from the camera.

By default, the camera operates at the maximum f_{CLK} frequency. The software reconstructs the binary frames from the photon event data and then accumulates them to create grayscale images corresponding to an integration time or frame rate selected by the user. The default integration time is 100 ms but can be set to any custom value ranging from nanoseconds to seconds. Alternatively, the user can input the desired frame rate.

The interface currently supports 7 modes of displaying the resulting grayscale images and defaults to the *Normalized* view. Table 1 summarizes the effect of each display mode on the original pixel data $I(X, Y)$ from the grayscale image I . The *Events* mode is special because it does not display an image but a 3D scatter plot of the raw (X,Y,T) photon event data, as shown in Figure 6. However, due to display limitations, not all of the events can be shown.

Display mode	Effect
Normalized (default)	$I_N(X, Y) = 255 \times I(X, Y) / \max(I)$
Logarithmic	$I_L(X, Y) = 255 \times \log_{10}(1 + I(X, Y)) / \max(\log_{10}(1 + I))$
8-bit	$I_8(X, Y) = 255 \times \min(I(X, Y), 255) / 255$
10-bit	$I_{10}(X, Y) = 255 \times \min(I(X, Y), 1023) / 1023$
12-bit	$I_{12}(X, Y) = 255 \times \min(I(X, Y), 4097) / 4097$
16-bit	$I_{16}(X, Y) = 255 \times \min(I(X, Y), 65535) / 65535$
Events	(X,Y,T) scatter plot

Table 1: Display modes supported by the NovoViz interface.

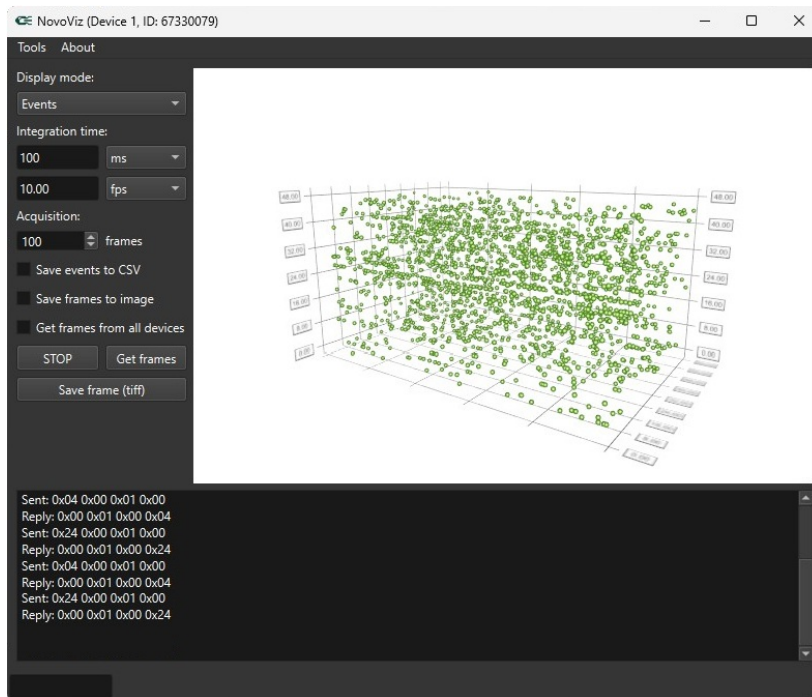


Figure 6: The *Events* display mode outputs a 3D scatter plot of the raw (X,Y,T) photon event data instead of an image.

A live view of the resulting grayscale images acquired at the selected integration time / frame rate and display mode is enabled by pressing the *LIVE* button. Pressing the *STOP* button will disable the stream and leave the last image on screen, which can be saved as a *.tiff* file by pressing the *Save frame (tiff)* button.

Alternatively, a specific number of frames (default 100) can be acquired under the current integration and display settings by pressing the *Get frames* button while the stream is live and *Save frames to image* is selected. The software will output a *.tiff* stack file in the current directory with a *frames_YYYYMMDD_hhmmss.tiff* naming convention. Selecting *Save events to CSV* will create a four column *frames_YYYYMMDD_hhmmss.csv*

file with the raw data from the sensor as described in Chapter 3. The options can be enabled simultaneously to get both an image stack and raw photon events.



The output *.tiff* stack is affected by the current display mode. Only the *.csv* file contains raw data.

6.2 Clock configuration

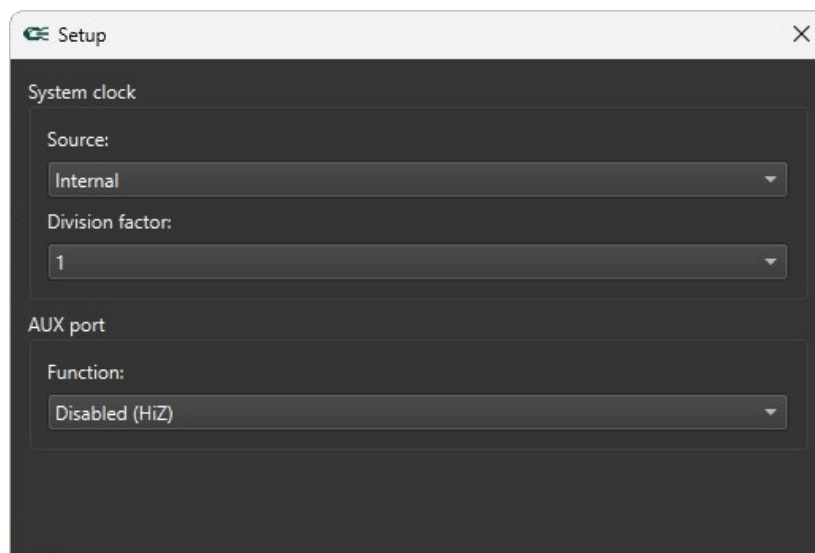


Figure 7: Setup interface used to configure the system clock and auxiliary port.

System clock settings can be changed by accessing the setup menu via *Tools* → *Setup*. By default, the internal 100 MHz oscillator is used as a source, but if the user needs to synchronize the camera to an external reference, the *AUX port* can be selected instead. Regardless of which source is selected, various division factors or a 180 deg shift can be applied to the signal. Optimal performance is achieved at the maximum f_{CLK} frequency, whereas slow frequencies can result in false events due to leakage in the pixel bus.



The *System clock (IN)* AUX port function needs to be selected when the system clock source is set to *AUX port*.

6.3 Pixel masking

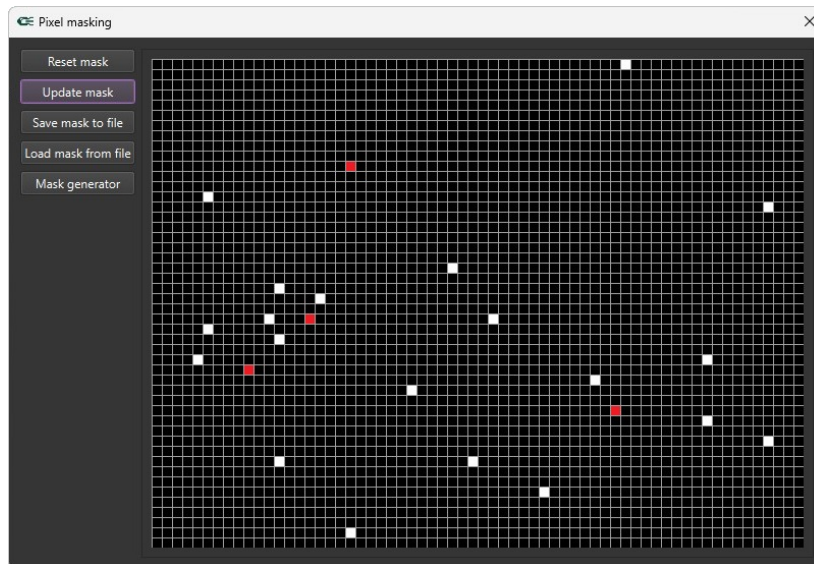


Figure 8: The pixel masking interface of the NovoViz Camera software.

The NV04ASC sensor offers the possibility to mask any arbitrary pixel in order to ignore hot pixels or to limit the ROI. This functionality is accessed in the NovoViz Camera software via *Tools* → *Pixel masking* which opens the menu shown in Figure 8.

The system starts with all pixel masks disabled. The large interactive grid allows the user to manually select which pixels to be masked while also showing which pixels are currently masked (white pixels). Pressing the *Update mask* button will send the new mask requests (red pixels) to the sensor which will then be implemented. This process can be repeated at the user's discretion. The masking map can be exported or imported by using the *Save mask to file* or *Load mask from file* buttons.

Pressing the *Reset mask* button will disable all the pixel masks, not just the current selection.

The software provides an additional function via the *Mask generator* interface shown in Figure 9. In this case, the current image displayed in the main window can be used in combination with an adjustable threshold to mask all pixels above a specific value. This can be used during the initial system setup to mask the hot pixels after acquiring a long exposure dark frame.

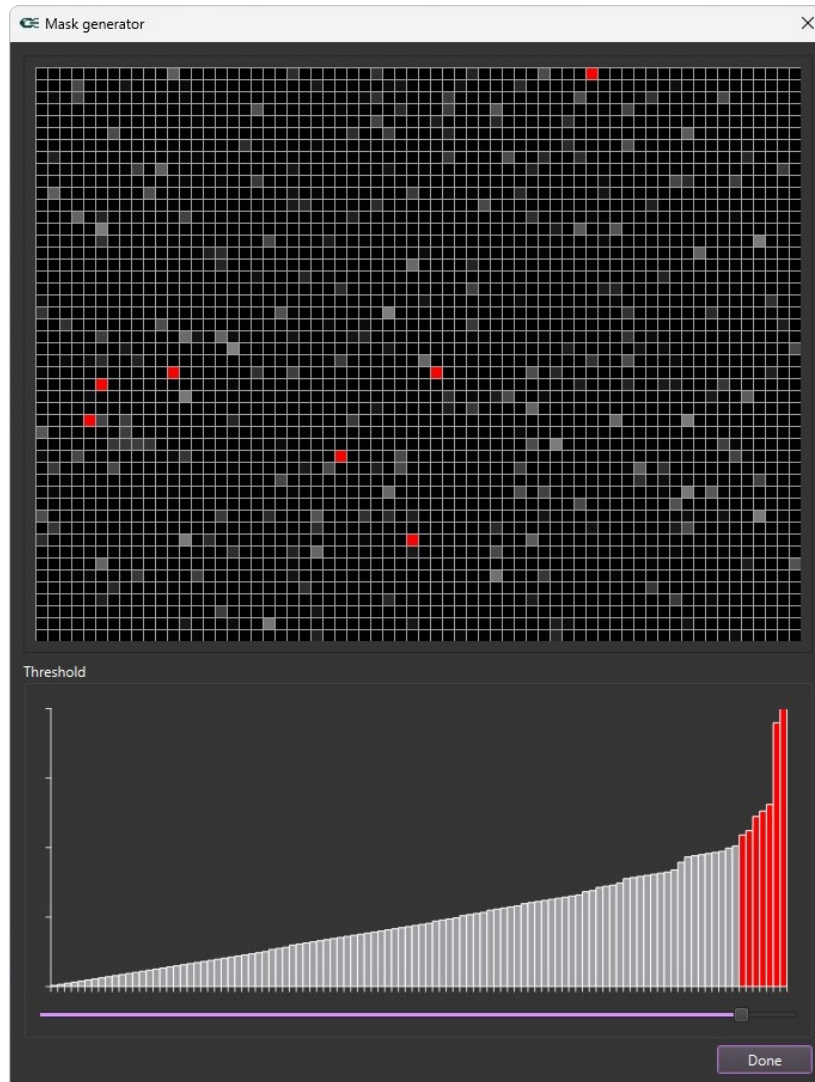


Figure 9: The pixel mask generator interface allows the user to mask all the pixels in the currently displayed image that have a value above a specific threshold.

6.4 AUX port

The SMA port on the back of the camera can be used as a user defined auxiliary port. For protection, at startup, it is configured as a high impedance input. The various functions can be selected from the *Tools* → *Setup* menu and are summarized in Table 2.

Function	Description
Disabled (HiZ) (default)	High impedance input port.
System clock (OUT)	Output for the internal system clock at the current division factor.
Frame marker (OUT)	Output for the current F bit value in the output data, with a period equal to twice the integration time and a 50% duty cycle.
Frame pulse (OUT)	A pulsed output coinciding with every change of the F bit value in the output data, with a period equal to the integration time.
Event flag (OUT)	A flag signal that is high when an event is detected in the pixel array.
System clock (IN)	Input reference signal that will be used as a system clock after applying the current division factor. Must be selected when the clock source is not internal.
Frame marker (IN)	The value of this input signal determines the value of the F bit in the output data.
Frame pulse (IN)	A rising edge of this input signal will toggle the F bit in the output data.

Table 2: Functions of the auxiliary SMA port.

6.5 Saving current configuration

After completing all the desired configuration steps, the current state can be exported for later use by selecting *Tools* → *Save configuration*. The file can then be imported at any time by selecting *Tools* → *Load configuration*. This will automatically change the display mode, integration time, number of frames and output data type, clock and auxiliary port setup and the pixel masks.

6.6 Operating multiple cameras

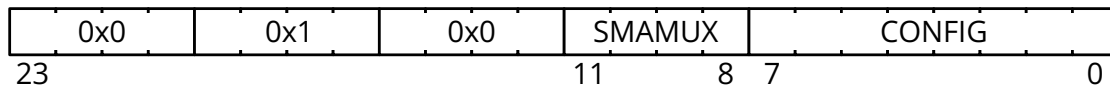
The NovoViz Camera software supports simultaneous operation of multiple cameras. The user needs to start a new instance of the software after connecting every device. If multiple cameras are detected, the user will be asked to select a specific device ID. Each camera can be configured and operated independently. If simultaneous acquisition is desired, the *Get frames from all devices* option needs to be selected on the main interface. Pressing *Get frames* will then result in the launch of all acquisition cycles. The cameras can have different configurations, for example number of frames or integration times.

7 Operating the camera using external scripts

The NV04ASC-HW Asynchronous camera uses an FTDI FT601Q USB controller and as a result, it can interface with a multitude of programming languages and operating systems through third party drivers. Camera configuration and data transfer is implemented using a command-based interface where the host sends 3-byte instructions and the camera system responds either with an acknowledge packet or a continuous stream of data.

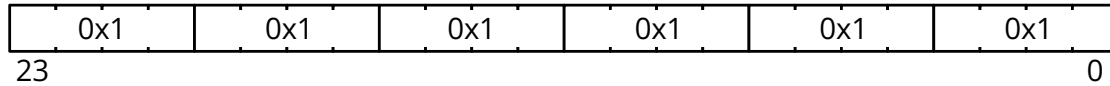
7.1 Configuration, version and ID commands

System & AUX port configuration command

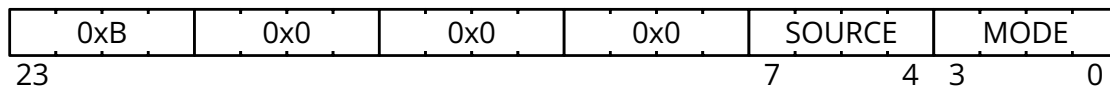


The system will reply with a 3-byte answer identical to the command sent by the user.
 Possible values and their meaning:

SMAMUX	
0	AUX port disabled (HiZ INPUT); Default.
1	AUX port is output; System clock.
2	AUX port is output; Frame marker.
3	AUX port is output; Frame pulse.
4	AUX port is output; Event flag.
5	AUX port is input; System clock.
6	AUX port is input; Frame marker.
7	AUX port is input; Frame pulse.
8 - 15	RESERVED
CONFIG	
bit0	RESERVED; Set to 0.
bit1	RESERVED; Set to 0.
bit2	Enable sensor CLK; Set to 1 for normal operation.
bit3	RESERVED; Set to 0.
bit4	RESERVED; Set to 0.
bit5	Enable event stream. Set to 1 to start acquisition.
bit6	RESERVED; Set to 0.
bit7	RESERVED; Set to 0.

Get module ID and firmware version command


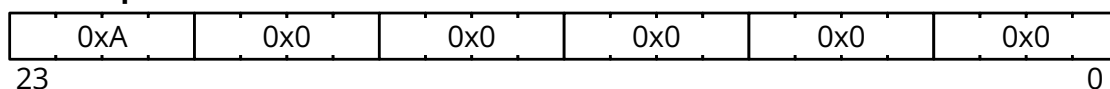
The system will reply with a 3-byte answer containing the module ID (bit23 down to bit8) and the firmware version (bit7 down to bit0).

CLK configuration command


The system will reply with a 3-byte answer identical to the command sent by the user.
 Possible values and their meaning:

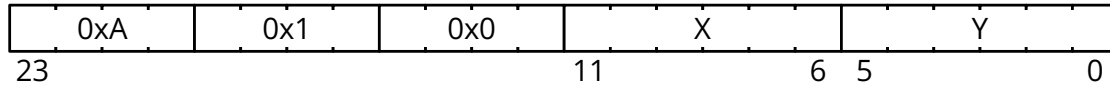
SOURCE	
0	100 MHz internal reference; Default.
1	AUX port.
2 - 15	RESERVED; Set to 0.
MODE	
0	Identical to the clock source; Default.
1	Clock source frequency divided by 2.
2	Clock source frequency divided by 4.
3	Clock source frequency divided by 6.
4	Clock source frequency divided by 8.
5	Clock source frequency divided by 10.
6	Clock source frequency divided by 12.
7	Original clock source frequency with 180° phase shift.
8 - 15	RESERVED; Set to 0.

7.2 Pixel masking commands

Disable pixel masks command


The system will reply with a 3-byte answer identical to the command sent by the user.

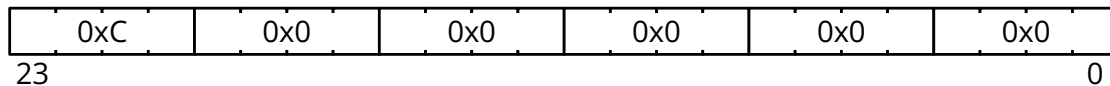
Mask specific pixel command



The system will reply with a 3-byte answer identical to the command sent by the user. *X* and *Y* are the column and row index, respectively.

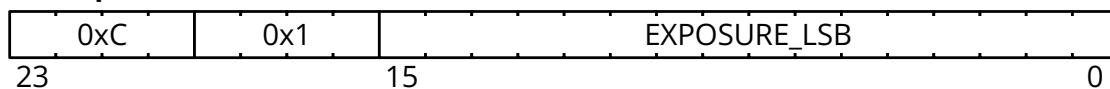
7.3 Exposure commands

Reset exposure command



The system will reply with a 3-byte answer identical to the command sent by the user.

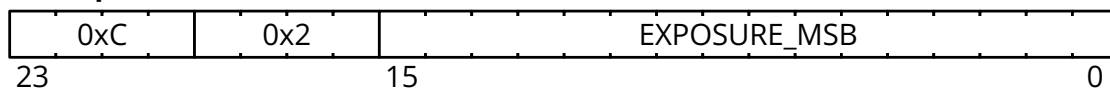
Set exposure LSB command



The system will reply with a 3-byte answer identical to the command sent by the user. The switching frequency of output flag *F* is equal to:

$$T_{EXP} = 2 \times T_{SYSCLK} \times (2^{16} \times EXPOSURE_MSB + EXPOSURE_LSB)$$

Set exposure MSB command

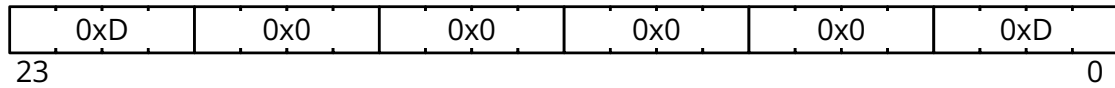


The system will reply with a 3-byte answer identical to the command sent by the user. The switching frequency of output flag *F* is equal to:

$$T_{EXP} = 2 \times T_{SYSCLK} \times (2^{16} \times EXPOSURE_MSB + EXPOSURE_LSB)$$

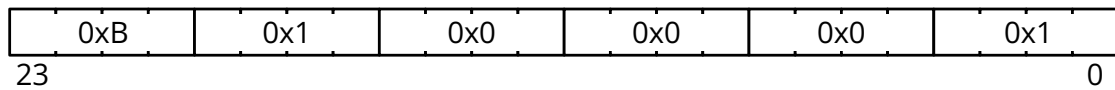
7.4 Miscellaneous commands

Reset NV04ASC chip command



The system will reply with a 3-byte answer identical to the command sent by the user.

Flush camera FIFO command



The system will reply with a 3-byte answer identical to the command sent by the user.