NVx5VFR-HW Variable frame rate SPAD camera

Features

- **480×320 or 256×192 SPAD array**
- **Event-based readout**
- **Global shutter**
- **On-chip pixel binning**
- **Adjustable event threshold**
- **Single USB-C for power and data**

Applications

- **Quantum imaging**
- **Machine vision**
- **Low light imaging**
- **High dynamic range imaging**
- **Depth sensing**
- **Bioimaging**
- **Visual odometry**

Description

The NVx5VFR-HW variable frame rate camera was developed for applications requiring high sensitivity and/or frame rate but with reduced output bandwidth. It is built around the NovoViz NVx5VFR variable frame rate single-photon avalanche diode (SPAD) sensor.

The system combines benefits of a SPAD camera, namely the single-photon resolution and fast operating speeds, with those of an event camera – low output data rates. The innovative sensor architecture streams photon events detected during an exposure cycle down to nanosecond timestamp resolution with reduced latency over a conventional, low-cost USB interface.

The camera only sends out the pixels which have registered a photon event during the exposure period and can immediately proceed to the next acquisition cycle when all the events are accounted for. The threshold for generating an event can be adjusted from 1 to 15 photons, depending on the pixel binning scheme. This photon event-driven output reduces the system output data rate and power consumption. If a fixed frame rate is desired, the camera remains inactive after the event readout is finished until the appropriate time interval has passed.

Contents

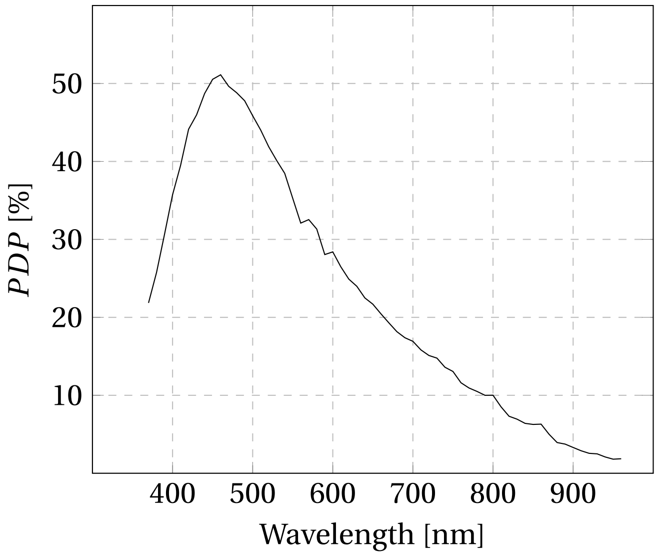
1 Absolute maximum ratings

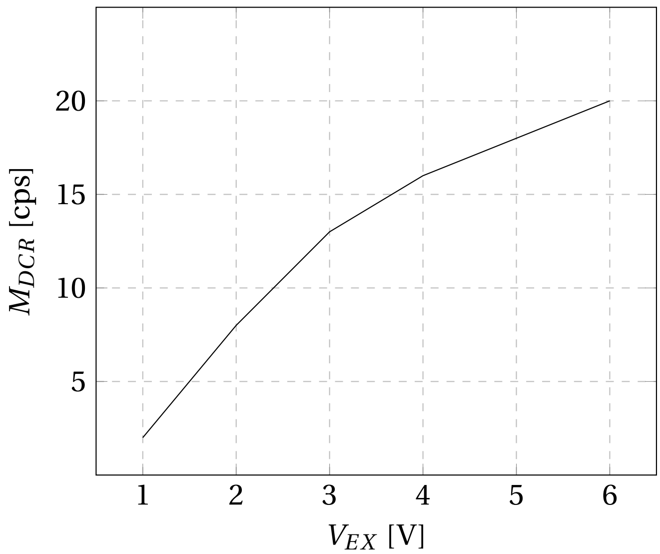
		MIN	MAX	UNIT
V_{DD}	Supply voltage	4.5	5.5	V
V_{EX}	Excess bias voltage		6	V
P_{peak}	Peak power consumption		2000	mW
T_A	Operating temperature	10	85	°C
f_{CLK}	System clock frequency		25	MHz

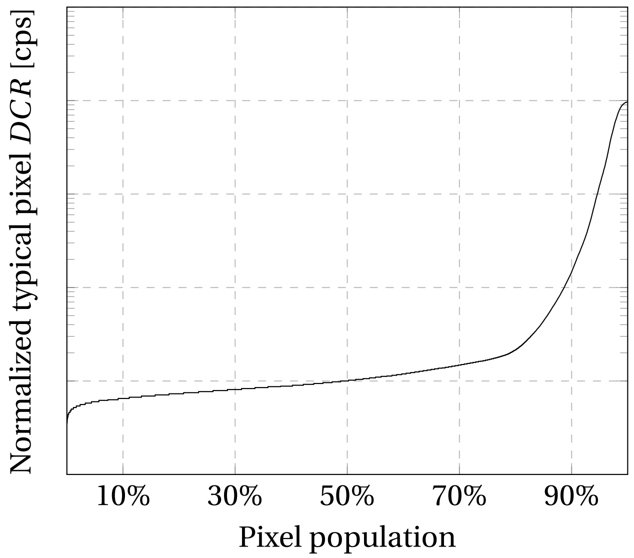
2 Specifications

		COMMENT	MIN	TYP	MAX	UNIT
	Array format	NV15VFR-HW NV05VFR-HW		480×320 256×192		pixels pixels
P_P	Pixel pitch			20		µm
P_Φ	Pixel sensitive area diameter			5		µm
P_{FF}	Pixel fill factor	Native		4.9		%
P_{XTP}	Pixel crosstalk probability				2	%
PDP	Photon detection probability	λ=450 nm, V_{EX}=6 V			50	%
λ_w	Wavelength window	PDP>10%, V_{EX}=6 V	350		800	nm
M_{DCR}	Dark count rate (median)	T_A=27 °C, V_{EX}=6 V		20		cps/pxl
HPP	Hot pixel percentage	$DCR > 100M_{DCR}$		10		%
DPP	Dead pixel percentage			0.03		%
W_G	Global shutter width			20		ns
T_{EXP}	Exposure time		W_G			ns
TP_{min}	Minimum frame processing time	Zero events/frame	200			ns
F_{max}	Maximum frame rate	Zero events/frame $T_{EXP} = W_G$		2.3		Mfps
D_{rate}	Output data rate				200	MB/s
	Output data format			32		bit
	Pixel binning format		1×1		8×8	pixels
	Event threshold	1×1 binning 2×2 binning 4×4 binning 8×8 binning	0 0 0 0		0 3 15 15	photons photons photons photons

3 Typical characteristics







4 Detailed description

The NVx5VFR-HW system is variable frame rate single-photon camera with an event-driven output, based on the NovoViz NVx5VFR sensor. Similarly to an event camera, the output does not consist of frames, so it occupies significantly less output bandwidth, but is dependent on photon flux. Each photon detection inside the exposure period will result in an output event being sent via the USB3.0 interface to the host during the readout period. If there are no photon events, the camera can advance to the next exposure period after 200 ns. If a fixed frame rate is desired, the camera remains inactive after the event readout is finished until the appropriate time interval has passed.

The sensor does not contain a time to digital converter (TDC) but instead has a 20 ns global shutter/gate. When a photon is detected by one of the pixels, the timestamp corresponding to the current exposure is recorded and attached to the pixel location information.

The output event stream can be processed by the user in order to generate binary frames at a variable/-fixed frame rate calculated by subtracting the difference between consecutive timestamps. Additionally, the binary frames can be accumulated into grayscale frames of various bit depths or logically OR-ed into binary frames of specific exposure lengths.

The pixel array can be binned on-chip in four different configurations, namely 1×1, 2×2, 4×4 and 8×8. This results in a change in the array format to 480×320, 240×160, 120×80 and 60×40 pixels,respectively, and an increase in the pixel dynamic range to 1-bit, 2-bit, 4-bit and 6-bit, respectively. When binning, the threshold level for generating an event can be changed with 1-photon steps, between 0 and 15, depending on the dynamic range of the pixel. A group of binned pixels will not generate an output event unless the total number of photon detections is greater than the selected threshold value. The effect is a reduction in output data rate and DCR masking.

4.1 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 an exposure timestamp T. Additionally, when binning, a count value C indicates the total photon detection in the pixel group. A zero value of C represents that all of the pixels in the group have fired. A marker word is sent after the final event has been read, which allows easy binary frame separation. The following figures show the bit allocation of the 32 bits of the output event for different binning configurations.

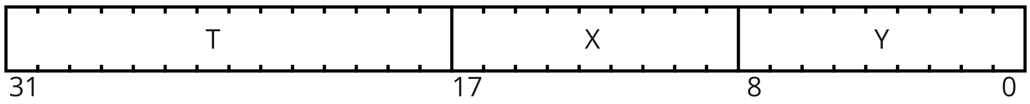


Figure 1: Composition of the 32 bit output event during 1 × 1 binning.

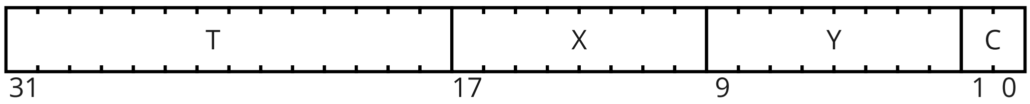


Figure 2: Composition of the 32 bit output event during 2 × 2 binning.

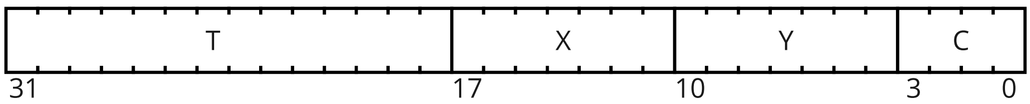


Figure 3: Composition of the 32 bit output event during 4 × 4 binning.

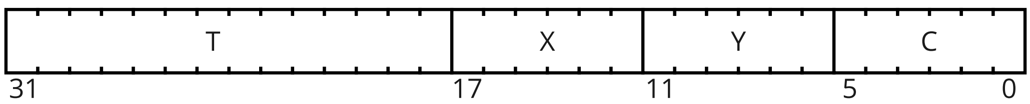


Figure 4: Composition of the 32 bit output event during 8 × 8 binning.

4.2 Operation

The sensor is designed to operate in a repeating cycle of two steps: exposure and readout. The duration of the exposure cycle is determined by the user and can be as short as 20 ns. Only photon arrivals within the gate are recorded. Consecutive openings of the gate are possible but the photon arrivals will be OR-ed together into a single binary frame. At the end of the exposure step, the camera enters readout mode, where the on-chip arbitrer processes the pixel data. A minimum of 200 ns is necessary for the system to determine if there are events that need to be read out or if no photons were detected during the previous exposure. If there is data, the output stream will start, and the events can be read sequentially until all of the pixels were processed. When readout is finished, or if after the initial processing time, no events are detected, the next exposure cycle can immediately begin. The duration of the readout step is thus dependent on the photon flux, but can be constrained to a specific value by having the camera in stand-by until the required time has passed.

Event readout is performed based on a priority order as shown in Figure 5. The sensor operates as two independent halves and during readout, the output values alternate between the two sections. For maximum readout speed, the scene should be framed such that the photons are uniformly distributed across the two halves.

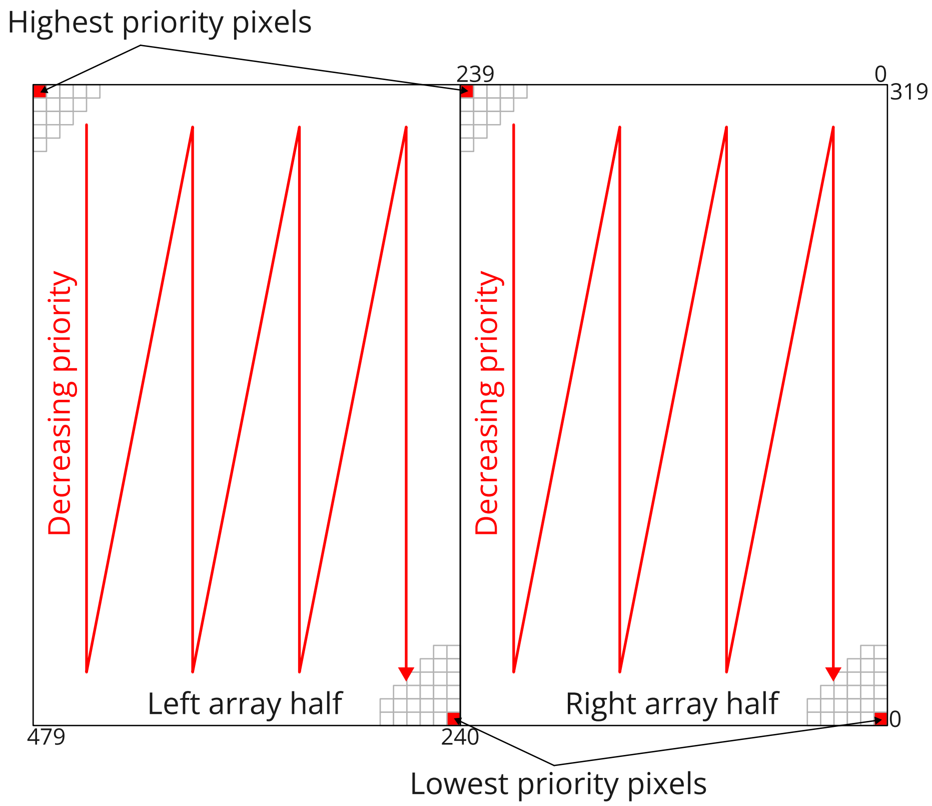


Figure 5: Pixel priority map used by the arbitrer circuit when reading the pixel events in the NV15VFR sensor. An identical map is used for the NV05VFR, but the number of columns and rows is reduced.

4.3 Pixel masking

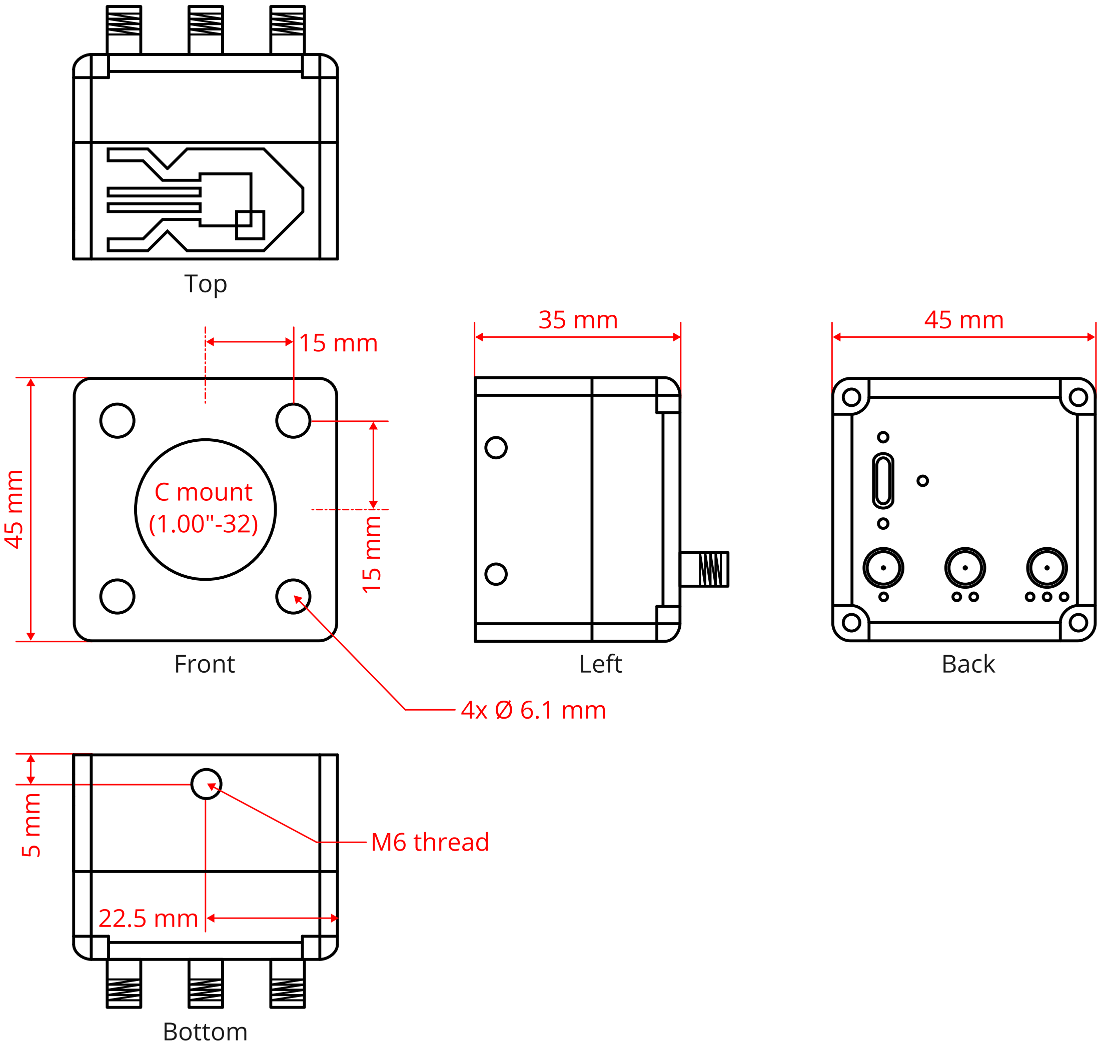
The NovoViz NVx5VFR sensor supports full custom pixel masking. Any pixel can be masked based on its $X - Y$ address but the settings are volatile and will be erased after restart. Additionally, all the masks can be cleared simultaneously across the entire array. There is, however, no equivalent method of masking all the pixels at once, and instead the user needs to sequentially mask them. It is recommended that before running the target application, the user masks the hot pixels in order to decrease the readout time and increase the frame rate.

4.4 Auxiliary ports

Apart from the USB-C connector, the camera possesses three SMA auxiliary ports that function as user-defined inputs/outputs. These signal can be used for external synchronisation purposes, among others. The default state is HiZ input.

5 Mechanical details

5.1 NVx5VFR-HW-C - C/CS-mount variant



6 Resources

6.1 Documentation updates

The latest documentation can be found on the specific product page on www.novoviz.com. Please take note of the current document version and review the revision history included in the updated documentation.

6.2 Support

For inquiries please use the contact form on www.novoviz.com.

7 Ordering

Part number	Description
NV15VFR-HW-C	480×320 SPAD array; C/CS-mount optical port version
NV05VFR-HW-C	256×192 SPAD array; C/CS-mount optical port version

The NVx5VFR-HW comes complete with the latest firmware and a short USB cable. Visit www.novoviz.com to download the necessary software. The objective is not included. The camera has a C-mount thread input port that requires a 10 mm spacer for C-mount objectives or a 5 mm spacer for CS-mount.

The SPAD V_{EX} is fixed at 6 V, but the user has the choice to order a custom camera version, depending on their application needs.

8 Notice and disclaimer

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ESD caution

This device is vulnerable to damage from electrostatic discharge (ESD). NovoViz recommends that all devices be handled using proper ESD precautions. Failure to follow correct handling and installation procedures may result in damage. ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits are often more susceptible, which may cause the device to fail to meet published specifications.

