ADVAPIX TPX3
Direct detection Si and CdTe cameras

The first truly spectral imaging detector in the world

- Uncompromised spectral imaging
- Event-driven readout
- Recording a list of all events rather than just images
- Position, energy and time-of-arrival is measured for every detected quantum

The next generation of radiation imaging detectors for recording:

- Position
- Energy/wavelength
- Time-of-arrival

Model No.:	**APXMD3-Xxx170704** **APXT3M-Xxx180119** **APXT3M-Xxx200128** **APXT3M-Xxx201030**

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Imaging the Unseen

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Key features	
Readout chip type	Timepix3
Pixel size [3]	55 x 55 µm
Sensor resolution	256 x 256 pixels
Time resolution	1.6 ns
Power	External 5V
Sensor material	100, 300, 500 µm Si, 1000 µm CdTe
Dark current	none
Interface	USB 3.0 (Super-Speed)
Maximum readout speed	38 million pixels / s
Dimensions	210 x 94 x 38 mm
Weight	905 g

The ADVAPIX TPX3 modules were designed with special emphasis to performance and versatility which is often required in a scientific experimental work. They contain CERN detector Timepix3 for particle tracking and imaging with Si or CdTe sensor. The ADVAPIX TPX3 modules can be used in different configurations: telescope of several layers for better particle tracking and/or side-by-side for larger area coverage. Each module contains one Timepix3 device with fast sparse data readout to acquire up to 38 Mhits per second. A separate USB 3.0 channel for each module assures fast read-out of the whole modular system. The sensor type and thickness is of customer's choice.

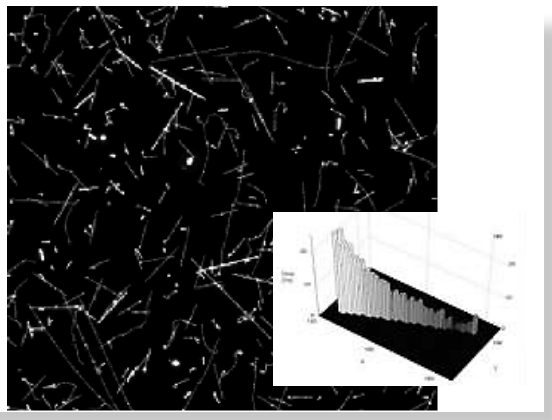

Illustration of single particle sensitivity of Timepix3 device. The tracks of different particles of radiation background (mostly muons and few protons) were recorded in 5 minutes on board of airplane. No noise (clean zero) is seen in dark regions. Inset shows the time profile along one muon track.

The typical and intended applications of ADVAPIX TPX3 include:

- **Spectral X-ray and gamma ray imaging**: X-ray fluorescence imaging, X-ray radiography (low flux), scintigraphy or SPECT, radiography with isotopes.
- **Energy dispersive XRD, SAXS or WAXS**: Monochromatic X-ray source is NOT needed! Even high energy for thick samples is possible (e.g. 100 keV)!
- **Particle tracking and ion beam monitoring**: detectors can be used for tracking and tagging of primary particles (e.g. ions) as well as secondary radiation (spallation, fragmentation, recoiled, bremsstrahlung, prompt/delayed decays, neutrons[1]...).
- **Neutron imaging**: The sensors can be adapted for neutron imaging by deposition of converter layers[2].

Recording shapes of individual hits together with advanced data processing allows increasing the spatial resolution in some applications to units of microns or even sub-micrometric level (for ions).

[1] ADVAPIX TPX3 is not certified dosimetric device. It serves as the first level indicator and monitor of radiation fields allowing identification of a radiation type. Radiation protection of people cannot be based on measurements of ADVAPIX TPX3.

[2] Convertors based on ^{6}LiF or ^{10}B$_4$C for slow neutrons (efficiency up to 4%) or PE for fast neutrons.

[3] 552 x 110 µm at the edges and 110 x 110 µm at the corners

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Device parameters

Operating conditions				
Symbol	**Parameter**	**Value**	**Units**	**Comment**
T_a	Operating ambient temperature range	0-50	°C	
Φ	Humidity	<80	%	Not condensing
IP	IP rating with cover	IP40		
IP	IP rating without cover	IP10		
[1] With temperature stabilization – see the paragraph below.				

External temperature stabilization

Temperature stabilization of the device required. Attach the back of the device to a water-cooled plate or to a Peltier module. The temperature should be set to 22 °C.

- Intended for dust free indoor use.
- The device will automatically shut down after chip or CPU temperature exceeds 55 °C.

Electrical specification

T_{def} = 25 °C, USB voltage V_{CC} = 4.8V

Symbol	Parameter	Min	Typ	Max	Units	Comment
V_{CC}	Supply Voltage	4.0	5.0	5.5	V	
I_{CC1}	Chip active		800	1500	mA	
P1	Power Dissipation			7.5	W	
I/O Conn. Input CMOS 2.5 V						
V_{INL}	Voltage Low	-0.3		0.7	V	
V_{INH}	Voltage High	1.7		2.8	V	
I/O Conn. Input LVDS						
V_{IN}	Voltage Range	0		2.5	V	
V_{INDIFF}	Differential Voltage	250		600	mV	
I/O Conn. +5 V (pin 2)						
I_{MAX}	Maximum current	0		0.5	A	
V_{+5V}	Pin Voltage		4.5		V	V_{CC} – 0.5 V
Bias Voltage Source for Sensor Diode						
V_{BIAS}	Bias Voltage	0		±450	V	Polarity is sensor dependent

Performance characteristics of Timepix3

Symbol	Parameter	Min	Typ	Max	Units	Comment
f	Hit-rate			38	MPixels/s	with USB 3.0 cable
	Data rate			2.4	Gbit/s	with USB 3.0 cable
T_{READ}	Frame readout time[1]		33		ms	with USB 3.0 cable
dT	Time resolution	1.56			ns	
F_{READ}	Read-out frequency		320		MHz	1/2 of maximum ROC freq
[1] During Readout time (or Dead time), no signal is collected from the sensor.						

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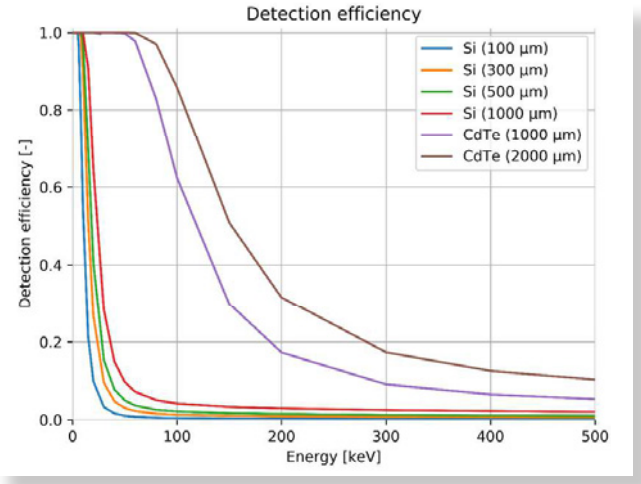
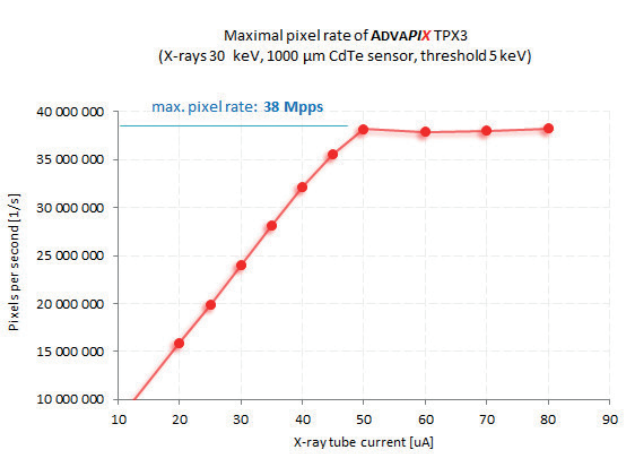
Pixel mode hit-rate measurement

The whole detector is exposed to homogenous perpendicular irradiation from X-ray tube operated at 30 kVp with 3 mm Aluminum filter. The measurement type is set to “Pixels” and mode to “ToT+ToA” The following setting must be set before the measurement starts. Uncheck the “ProcessData” and “DummyAcqNegativePolarity” and set value 400 to the field DDBlockSize and value 1000 to the field DDBuffSize in the tab Readout in More Detector Settings dialog which is accessible from the main PIXet Pro window on the right side under the panel Detector Settings. All other parameters are set to factory defaults (as stored in the configuration file delivered with the device). The exposure time is set to 1 s.

The data must be read out to the memory. The data are saved to disk after the measurement and later processed. The “Clustering” tool of PIXet Pro is used to analyze measured data where you can replay the data and find the total number of hit pixels.

The number of hit pixels per second is drawn as a function of X-ray tube current searching for saturation. The number of hit pixels per second is drawn as a function of X-ray tube current searching for saturation. The number of hit pixels per second is drawn as function of X-ray tube current searching for saturation.





Sensor parameters **T_{def} = 22 °C**								
Parameter	**Si**				**CdTe**		**Units**	**Comment**
Thickness	100	300	500	1000[1]	1000	2000[1]	µm	[1] Customized product
Calibrated energy threshold[2]	3,0	3,0	3,0	3,0	5,0	5,0	keV	[2] Premium calibration and/or chip class can achieve even better performance.
Energy resolution in ToT mode (σ @ 60 keV)	1.2 - 2.6	1.3 - 2.7	1.4 - 3.5	1.7 - 3.6	2.8 - 5.4	2.9 - 8.3	keV	
Energy resolution in ToT mode (σ @ 122 keV)					3.4 - 6.0	4.5 - 9.9	keV	
Typical detectable energy range for X-rays	3.0 - 60				5.0 - 500		keV	See chart Detection efficiency
Good pixels	> 99,5%				> 99,5%			
Pixel size	55 x 55						µm	[3] 55 x 110 µm at the edges and 110 x 110 µm at the corners

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Basic principles, measurement types and modes

The ionizing radiation particle interacts with the sensor material creating an electric charge. This charge is collected by electric field and brought to pixel preamplifier where it is amplified and shaped forming triangular voltage pulse. The amplitude and duration of this pulse is proportional to energy deposited by particle within the pixel. The situation when the voltage pulse amplitude in particular pixel exceeds preselected threshold value is called "event" or "hit".

Each pixel contains three digital counters (10, 14 and 4 bits). These counters are used differently according to measurement type and mode. There are four different quantities which can be measured and stored in counters of each pixel – these are selected by operational modes.

Measurement modes	
Number of events	number of events (hits) in the pixel during exposure time (this mode is suitable mainly for frame type readout).
Time-over-Threshold (ToT)	number of periods of 40 MHz clock signal (25 ns step) when amplifier output signal stays over the energy threshold. The ToT can be transformed to energy in keV using per-pixel-calibration function. The coefficients for per-pixel-calibration are unique for each pixel and they are stored in configuration file delivered with the device. The energy calibration is valid only for given values of other detector parameters as delivered in configuration file (especially threshold).
Time-of-Arrival (ToA)	number of periods of 40 MHz clock signal (25 ns step) from start of exposure till the event is registered by pixel (i.e. pulse in pixel crosses the threshold). The range is 409.6 µs. Additional 16 bits are added in FPGA in readout electronics so that the total range is 26.8 seconds. The additional bits are usable only if the pixel hit rate is below maximal value (see fp in table of Performance characteristics).
Fast-Time-of-Arrival (FToA)	time difference between event detection and next clock signal measured with step of 1.5625 ns. Range is 4 bits. The combination of ToA and FToA gives precise time of event detection in nanoseconds using following formula:
	Time [ns] = ToA x 25 - FToA x 1.5625

Measurement types	
Frame type measurement	No data is sent out of device during the exposure time. All measured events are accumulated in counters of pixels. Event counter is incremented, and ToT is integrated into iToT counter for all events. The measured data is read-out after end of exposure time for all pixels with nonzero content. No measurement can be performed during readout process. Measurement types in PIXet Pro: Frames, Integral.
Pixel type measurement	Information about all hit pixels is read-out immediately and continuously during exposure time. If hit rate is below maximal value (see f_p in table of Performance characteristics) then there is practically no deadtime. Measurement type in PIXet Pro: Pixels. Sometimes this mode is referred to as the data-driven mode or the event-based mode.

Combinations of operation modes and measurement types (rarely used cases are shown with blue background):

Type	**Mode**	**Range**	**Description**
Frame (reading all pixels after end of exposure)	ToA+ iToT	18 bit + 10 bit	2 output frames per exposure: ToA = Time of Arrival of first event in pixel, ToA and FToA[1] combined ToT = Time over Threshold, i.e. energy in keV if calibration is loaded and switched on
	ToA	18 bit	1 output frame: ToA = Time of Arrival of first event in pixel, ToA and FToA[1] combined
	Event +iToT	10 bit + 14 bit	2 output frames per exposure:
			events = number of events in pixel
			iToT = total time over threshold for all events in pixel
Pixel (reading only hit pixels continuously during exposure)	ToA +ToT	18 bit+ 10 bit	Data stream contains 4 values per pixel per event: Position, ToT, ToA and FToA[1] (for data formats .t3*)
	ToA	18 bit	Data stream contains 3 values per pixel per event: Position, ToA and FToA[1] (for data formats .t3*)
	Only ToT	10 bit	Data stream contains 2 values per pixel per event: Position and ToT (for data formats .t3*)

[1] ToA and FToA are combined by software automatically. For Pixel type measurement, if saved as a .t3pa file, ToA and FToA are stored as separate items.

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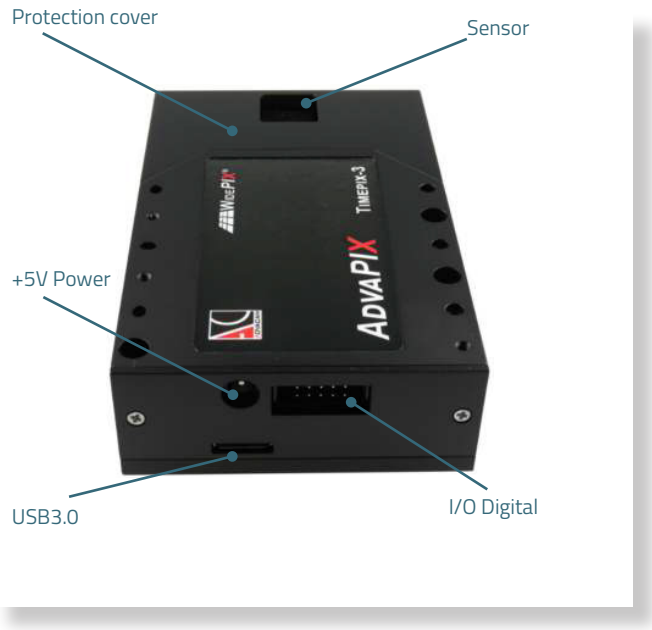
Device description



+5VDC connector
Main power supply (via standard 5.5/2.1mm barrel connector). Connect after plugging USB connector.

USB 3.0 connector
USB type micro B, Standard USB 3.0 Super-Speed.

I/O Digital connector
Signals on I/O Digital connector are used for synchronization purposes. For details see Synchronization guide for TPX3. Input pins are NOT +5V compatible. Pin 2 (+5V) may be used for power of external circuitry. It is taken directly from +5VDC connector, protected by schottky diode (0.5A max) Pin directions (Input/output) are dependent on polarity of pin 9 (Dir Select).

Table for version APXMD3-Xxx170704					
Pin	**Name**	**Signal type**	**Pin**	**Name**	**Signal type**
1	GND		2	+5V	
3	Reserved	CMOS 0-2.5V	4	Reserved	CMOS 0-2.5V
5	Reserved	CMOS 0-2.5V	6	Reserved	CMOS 0-2.5V
7	NC	-	8	Reserved	CMOS 0-3.3V
9	NC	-	10	Reserved	CMOS 0-3.3V

Table for version APXMD3-Xxx180119					
Pin	**Name**	**Signal type**	**Pin**	**Name**	**Signal type**
1	GND		2	+5V	
3	CLK p	LVDS (2.5V)	4	CLK n	LVDS (2.5V)
5	E2	CMOS 0-2.5V	6	E1	CMOS 0-2.5V
7	Trigger Out	CMOS 0-2.5V	8	Trigger In	CMOS 0-2.5V
9	Dir select	CMOS 0-2.5V	10	GND	

Table for version APXT3M-Xxx200128 & APXT3M-Xxx201030					
Pin	**Name**	**Signal type**	**Pin**	**Name**	**Signal type**
1	GND		2	+5V	
3	Master Disable	CMOS 0-2.5V/5V	4	CLK n	LVDS (2.5V)
5	CLK p	LVDS (2.5V)	6	T0/Sh-sel	CMOS 0-2.5V
7	Th/Sh p	LVDS (2.5V)	8	Th/Sh n	LVDS (2.5V)
9	Ready	CMOS 0-2.5V	10	T0/Sh-CMOS	CMOS 0-2.5V

Certificates

AdvaPIX TPX3 has been tested by certification authority (Electrotechnical testing institute EZÚ) according to following standards:

Standard number	Name
EN 61010-1:2010	Safety Requirements For Electrical Equipment For Measurement, Control, And Laboratory Use
EN 61326-1:13	Electrical Equipment For Measurement, Control And Laboratory Use - EMC Requirements

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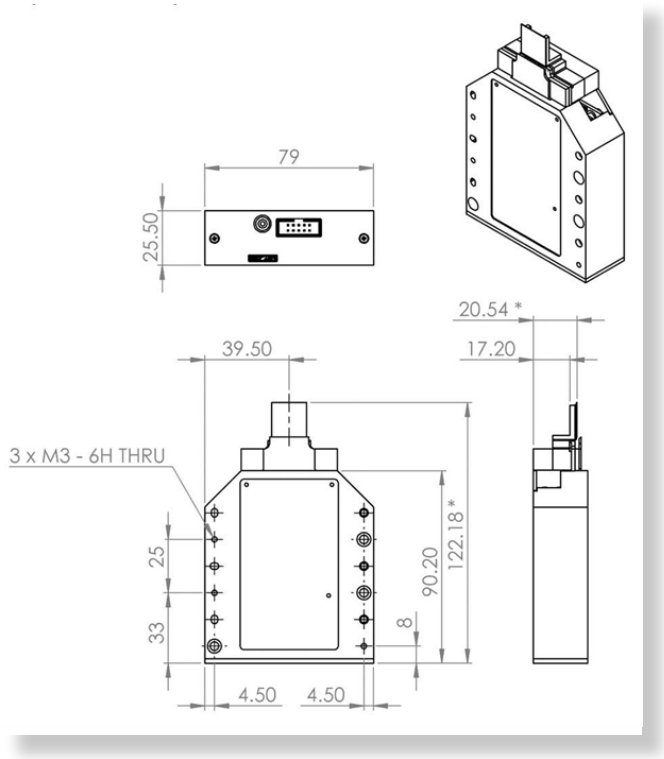
Mechanical dimensions

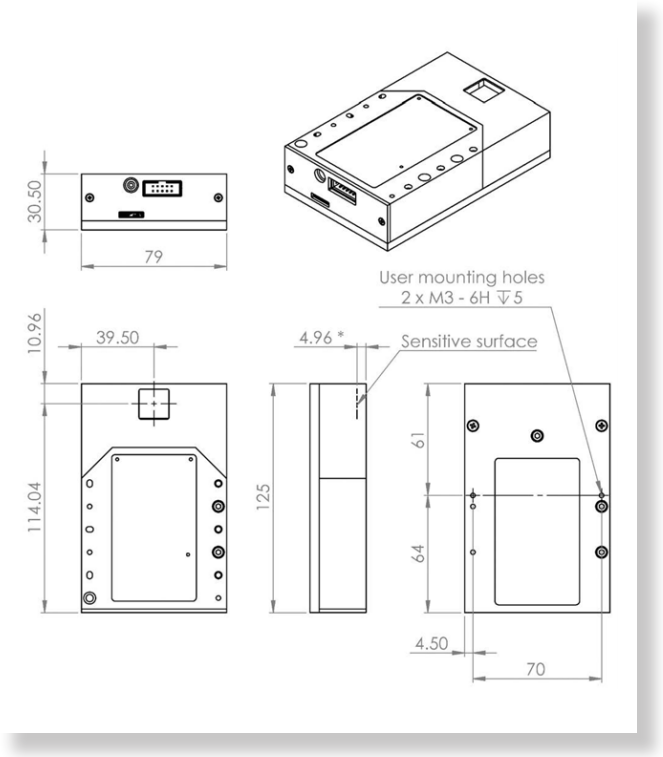
Without protection cover
Do not operate without protection cover!



All dimensions are in mm.

* Sensitive surface distance from bottom of the box is stated for 300 µm sensor thickness.

With protection cover



All dimensions are in mm.

* Sensitive surface distance from top of the box is stated for 300 µm sensor thickness.

Extreme care must be taken when removing protecting cover and handling the ADVAPIX TPX3 without the protecting cover. Warranty does not apply to mechanical damage of the sensor and wirebonds.

Model number codes (example)

APX	T3M	X	P	3	xxxxxxxx
Device name APX - AdvaPix	Device modification T3M (or MD3) Timepix3 module		Sensor type P - Planar silicon C - CdTe	Sensor thickness 1 - 100 µm 3 - 300 µm 5 - 500 µm A - 1000 µm B - 2000 µm	Device build version

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Instructions for safe use

To avoid malfunction or damage to your ADVAPIX TPX3 please observe the following:

- Do not expose to water or moisture.
- Do not disassemble. Wire-bonding connection may be irreversibly damaged.
- Do not insert any object into the sensor window.
- Extreme care must be taken when removing the protecting cover or handling the ADVAPIX TPX3 without the protecting cover. Warranty does not apply to mechanical damage of the sensor and wire-bonds
- The protection provided by this product may be impaired if it is used in a manner not described in this document

Do not touch sensor surface !

Release history

Date	Changes
17/11/02	Model number codes added, datasheet version
18/02/08	Synchronization of 180119 version
19/04/16	Synchronization voltages corrected
19/07/22	Major revision: Added intended applications, description of modes and types, hit rate
19/07/29	EMC certificate numbers added
19/12/04	Sensor parameters, Detection efficiency
20/05/19	New version; Mechanical dimensions; Changed Synchronization
20/11/11	Mounting holes for USB
22/06/06	Vacuum compatibility; sensor parameters
23/10/03	Parameters updated
24/02/15	Datasheet revision
24/07/02	New graphic style of the document, USB hub warning added
24/07/22	Minor format changes

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