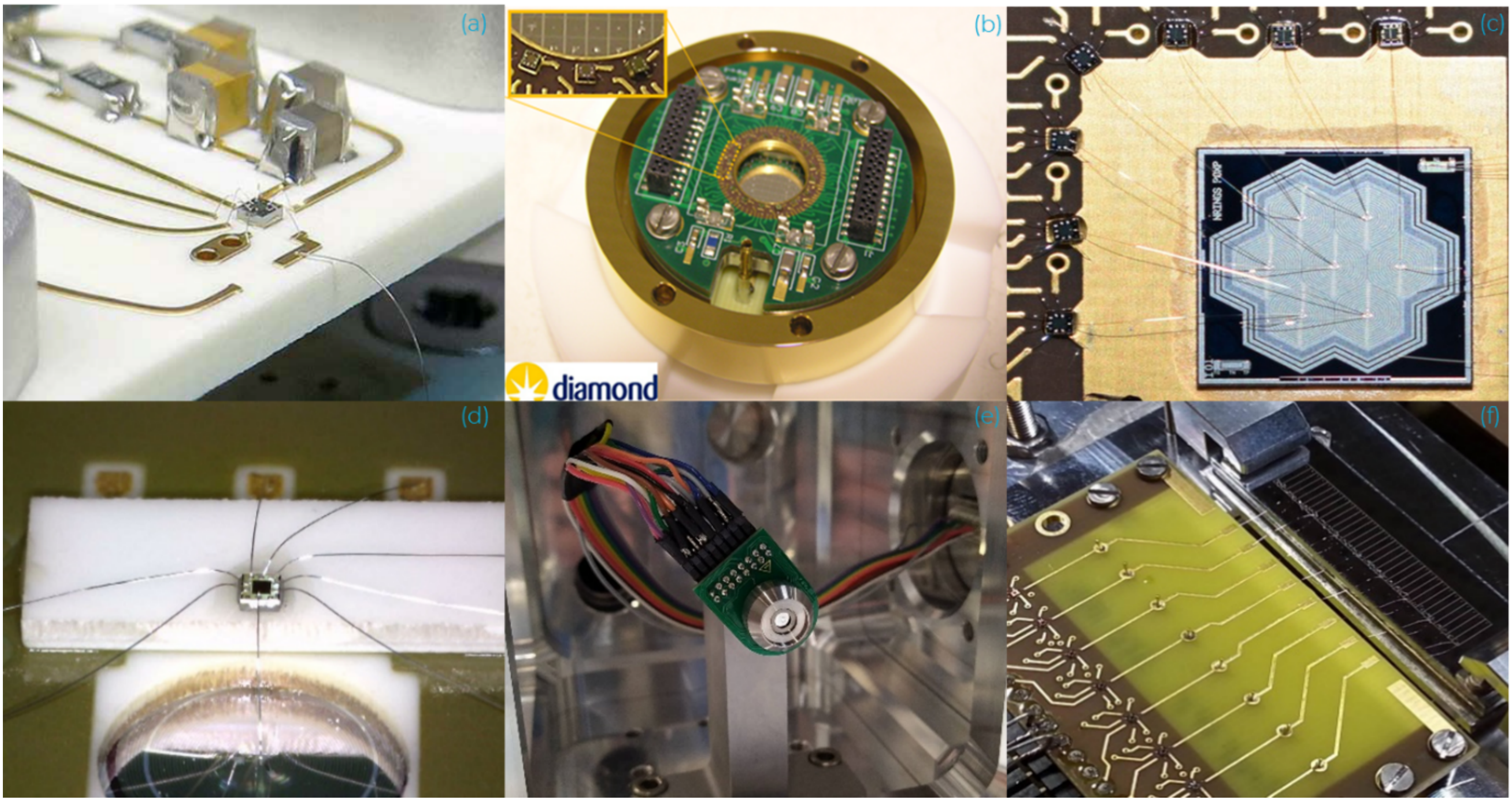
APPLICATION Note # 1
Find the right CUBE



Abstract

CUBE is a family of ultra-low noise CMOS preamplifiers for ionizing radiation detectors, featuring superior performance at short shaping times with respect to JFET front-end. Thanks to its extra-compact format, proven reliability, and ease-of-use, the CUBEs are compatible with most of the common solid-state sensors for spectroscopy. This document aims at providing clear guidelines on how to choose the right CUBE model for each application based on key parameters of the radiation detector you are using.

Figure references:
(a) Photo of a single CUBE preamplifier bonded on a ceramic board. Courtesy of Paul Barton, LBNL
(b) Photo of an array of 16 CUBE preamplifier wire-bonded to a multi-pixel Germanium detector. Courtesy of Nicola Tartoni, Diamond Light Source. See scientific reference [2]
(c) Photo of CUBE preamplifiers wire-bonded to a matrix of 7 SDD. Courtesy of Susanne Mertens, Max Planck Institut für Physik.
(d) Photo of a CUBE Preamplifier Wire-bonded to an SDD. Courtesy of Politecnico di Milano. See reference [4]
(e) Photo of an SDD assembled with a CUBE inside a TO8 package
(f) Photo of CUBE preamplifiers connected to an 8-channel Strip-detector. See reference [3]

Introduction

Since its introduction in early 2010s [1], CUBE disrupted the world of front-end preamplifiers for ionizing radiation detection, re-shaping the field of X-ray spectroscopy. Industrial and academic scientists profit from the techniques in the large family of atomic and nuclear spectroscopy. The large variety of available radiation sensor may pose a challenge at the time of choosing the preamplifier, namely the limiting factor for noise performances.

CUBE's unparalleled noise performance at short shaping/peaking times allows ultra-fast measurements, providing the right tool to cope with high radiation flux and enabling applications involving fast scanning (e.g. XRF mapping) without compromise in terms of energy resolution. As a designer, you only wish to be concerned about squeezing the ultimate performance out of your sensor. Whether you are looking for an ultra-low noise amplifier for low energy spectroscopy, or for a high-dynamic range front-end for gamma applications, you will love to discover how simply and reliably CUBE fulfils your needs.

After a quick description of the features common to every CUBE model, this document will guide you through the process of choosing the correct part for your application.

CUBE main characteristics

CUBE is a CMOS charge integrator circuit with pulsed reset. Thanks to its bare-die extra-compact format (750 µm x 750 µm x 750 µm), it allows for maximum assembly versatility. Easy-to-use and reliable, CUBE provides high signal level at the output of your detector module, avoiding any pick-up-prone external loop. Its output stage can drive up to 30 pF connection, making it suitable for a large variety of module architectures. CUBE main characteristics are listed in Table 1.

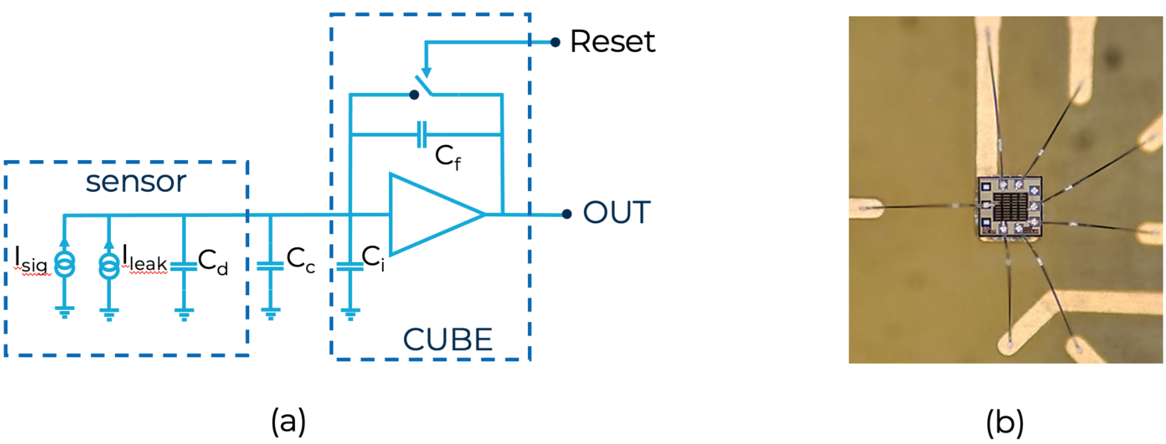


Figure 1. (a) Electrical schematic of the CUBE preamplifier connected to a generic sensor; (b) a CUBE PRE033 glued, and wire bonded to a board.

Table 1. CUBE main characteristics

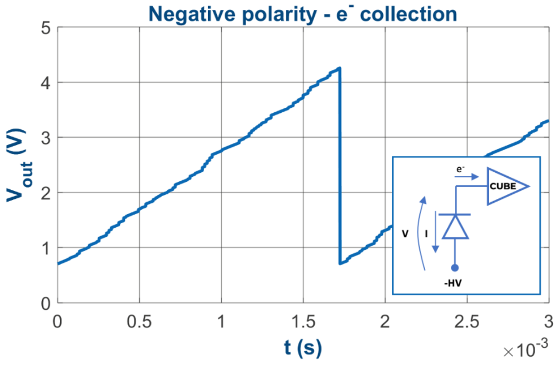
Parameter	Value
dimensions (width, length, thickness)	750 µm x 750 µm x 250 µm
detector input capacitance, C_d	from 0.1 pF to 10 pF
gain (for Si-sensor)	from 0.1 mV/keV to 1.8 mV/keV
temperature range	-60 °C / + 85 °C
vacuum compatibility	yes
Pad count (minimum)	7
Power consumption	20-90 mW
Power supply	5 V; 2 V; -6 V[1]
Output dynamic range	3.6 V[1]
Reset type	Pulsed[2]

How to choose the right CUBE model for your radiation detector?

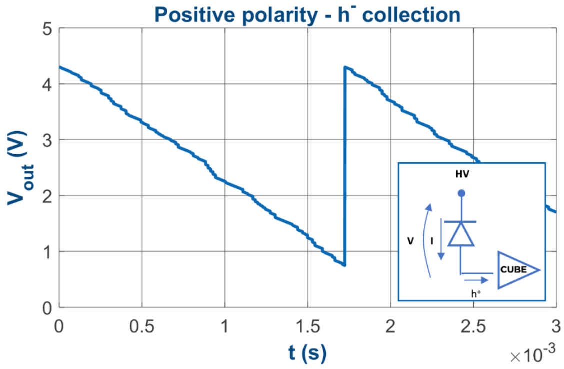
Among a vast variety of existing ionizing radiation sensors, the choice of the right CUBE model shall be made according to three main parameters:

1. Signal polarity.
   Does your detector collect electrons or holes? Depending on the biasing voltage applied between the cathode and the anode and on which of the two nodes the CUBE preamplifier is reading the signals, you may collect negative charges (electrons) or positive charges (holes). Depending on the radiation detector, it is typically recommended to choose one solution with respect to the other. In Table 2 below some examples are reported.

[1] Except for PRE_016 (Power supply: 3.3V, 2.0V, -6.0V; Output dynamic range: 2.0V)
[2] Continuous reset can be also used, if demanded by the application.



(a)



(b)

Figure 2. CUBE amplifier output in case of (a) electrons collection or (b) holes collection

Table 2. Example of radiation detectors and typical charge collection

Polarity	Typical detectors
Pos. (h+)	Si-PIN, Si-strips, HPGe
Neg. (e-)	SDDs, double-Strips, CZT, CdTe, HPGe

Depending on the charge collection chosen, the output of the CUBE preamplifier in pulsed-reset mode will present positive ramps (electrons) or negative ramps (holes) as reported in Fig. 2.

2. Detector capacitance

Achieving the best noise performance requires a proper capacitance matching between detector and preamplifier input. Thus, it is important to know the value of the input capacitance of the radiation detector to be readout. In Figure 3, typical ranges of input capacitances for various type of radiation detectors are reported.

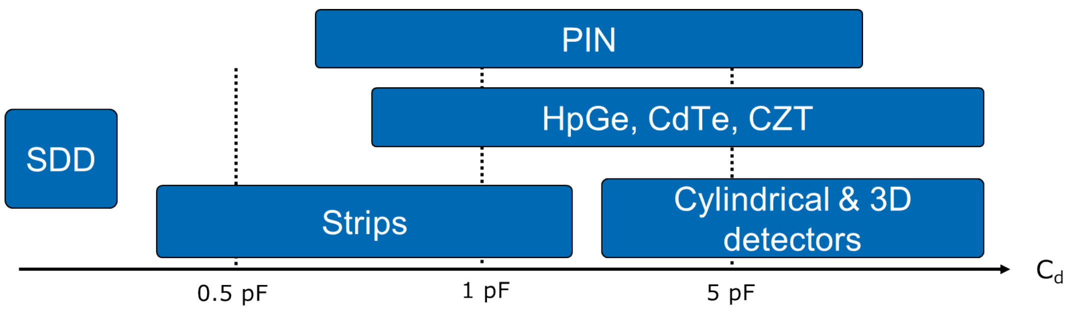


Figure 3. Input capacitance ranges for different radiation detector types

Different CUBE preamplifiers are available to match three different ranges of detector input capacitance:

- o Cd < 0.5pF
- o 0.5 pF < Cd < 3 pF
- o 3 pF < Cd < 10 pF

3. Dynamic range

Each application requires a given preamplifier sensitivity or a suitable input energy range. From a circuital point of view, this is achieved by means of a different feedback capacitance C_f in the preamplifier. Again, three main energy ranges are addressed with the CUBE family. The energy range of the radiation detector coupled with the CUBE preamplifiers can be thus calculated as the following:

$$Gain = \frac{q}{\varepsilon_m}\frac{1}{C_f} \cdot 10^6 \left[\frac{mV}{keV}\right]$$

$$Energy\ range = \frac{CUBE\ OUTPUT\ RANGE}{Gain} [MeV]$$

Where q is the charge of the electron, ε_m is the ionization energy of the detector material. In Table 3, the values of the CUBE Gain and the Energy range are reported for the three feedback capacitance values 25 fF, 50 fF, 500 fF. All the values are referred to Silicon and shall be scaled by the ratio of ionization energy R for different sensor materials, see Table 4.

Table 3. The three energy ranges of different CUBE models.

Cf	Gain (mV/keV)	Energy range (MeV)	Possible applications
25 fF	1.8/R	2*R	High res. XRF
50 fF	0.9/R	4 *R	Low res XRF, XRD, Gamma SPECT.
500 fF	0.09/R	40*R	Gamma, Beta, Neutron detection

Table 4. Ionization energies for common materials (absolute and normalized to Si)

Material	ε_m (eV/pair)	$R = \varepsilon_m / \varepsilon_{si}$
Si	3.6	1
Ge	2.9	0.8
Diamond	13	3.6
CdTe	4.4	1.2
CZT	4.6	1.3

Finally, in Table 5 a list of the available CUBE preamplifiers is reported together with their main features and possible application target.

Table 5. Table 5 . The CUBE preamplifiers family for different applications.

CUBE VERSION	POLARITY	DETECTOR CAPACITANCE	FEEDBACK CAPACITANCE	ENC (CUBE ONLY, 3.6EV/EL)	MAIN FEATURE	POSSIBLE APPLICATIONS
PRE_016	Negative (Electrons)	< 0.25 pF	25 fF	3.3 e- @1us	Very small detector capacitance, best energy resolution	Silicon Drift Detectors (SDD)
PRE_031	Negative (Electrons)	< 0.50 pF	25 fF	3.0 e- @1us	Small detector capacitance, excellent energy resolution, smallest dynamic range.	HpGe, CdTe or CZT
PRE_033	Negative (Electrons)	< 0.25 pF	25 fF	2.4 e- @1us	Very small detector capacitance, best energy resolution	Silicon Drift Detectors (SDD)
PRE_037	Positive (Holes)	< 0.70 pF	25 fF	4.0 e- @1us	Small detector capacitance, excellent energy resolution, smallest dynamic range.	Si-PIN, HpGe, Strip or pixelated detectors, X-ray applications
PRE_038	Positive (Holes)	0.50 pF – 3.00 pF	50 fF	12.3 e- @1us	Intermediate detector capacitance, good resolution, intermediate dynamic range.	Si-PIN, HpGe, Strip or pixelated detectors, X-ray applications
PRE_039	Positive (Holes)	3.00 pF – 10.00 pF	50 fF	20.2 e- @1us	Very large detector capacitance, good resolution, intermediate dynamic range.	Si-PIN, HpGe, Strip or pixelated detectors, X-ray applications
PRE_040	Negative (Electrons)	0.50 pF – 3.00 pF	50 fF	12.4 e- @1us	Small planar or pixelated detector, good resolution, intermediate dynamic range.	HpGe, CdTe or CZT, Strip or pixelated detectors, X-ray applications
PRE_041	Both (selectable)	3.00 pF – 10.00 pF	500 fF	57 e- @1us	Very large dynamic range, lower energy resolution.	HpGe, HpGe cylindrical, CdTe or CZT, Strip, Hard X-ray or Gamma applications
PRE_042	Both (selectable)	0.50 pF – 3.00 pF	500 fF	35.5 e- @1us	Very large dynamic range, lower energy resolution.	HpGe, HpGe cylindrical, CdTe or CZT, Strip, Hard X-ray or Gamma applications

Still in doubt? Contact us https://www.xglab.it/contact-us/.

References

[1] L. Bombelli, C. Fiorini, T. Frizzi, R. Alberti and A. Longoni, "“CUBE”, A low-noise CMOS preamplifier as alternative to JFET front-end for high-count rate spectroscopy," in *2011 IEEE Nuclear Science Symposium Conference Record*, Valencia, 2011.

[2] N. Tartoni, R. Crook, T. Krings, D. Protić, C. Ross, L. Bombelli, R. Alberti, T. Frizzi and V. Astromskas, "Monolithic Multi-Element HPGe Detector Equipped With CMOS Preamplifiers: Construction and Characterization of a Demonstrator," *IEEE Transactions on Nuclear Science,* vol. 62, no. 1, pp. 387 - 394, 2015.

[3] T. Krings, U. Spillmann, D. Protić, C. Roß, T. Stöhlker, G. Weber, L. Bombelli, R. Alberti and T. Frizzi, "Multi-element readout of structured HPGe-detectors for high-resolution x-ray spectroscopy using CUBE-preamplifiers," in *16th International Workshop on Radiation Imaging Detectors (IWORID)*, Trieste, 2014.

[4] G. Bellotti, A. D. Butt, M. Carminati, C. Fiorini, L. Bombelli, G. Borghi, C. Piemonte, N. Zorzi and A. Balerna, "ARDESIA Detection Module: A Four-Channel Array of SDDs for Mcps X-Ray Spectroscopy in Synchrotron Radiation Applications," *IEEE Transactions on Nuclear Science,* vol. 65, no. 7, pp. 1355 - 1364, 2018.