APOCAT – PMT and SiPM Readout ASIC for High-Rate X-ray Spectroscopy in Space

Dirk Meier, Joar Martin Østby, Hans Kristian Otnes Berge,
Jahanzad Talebi, Suleyman Azman, Jörg Ackermann, Ali Dadashi,
Amir Hasanbegovic, Jørgen Moe Sandvik, Jusong Choe, Jan-Erik Holter,
Tor Magnus Johansen, Arne Fredriksen, Gunnar Maehlum

Integrated Detector Electronics AS, Oslo, Norway

ABSTRACT

We present APOCAT, an integrated circuit (IC) for reading out spaceborne photon detectors, i.e., photomultiplier tubes (PMTs) and silicon photomultipliers (SiPMs). The circuit can be used in x-ray and gamma-ray detectors, for example, the advanced space-based solar observatory ASO-S [RD01]. ASO-S shall be launched in 2022 to study solar flares and coronal mass ejections on the Sun. APOCAT is related to SIPHRA, another SiPM/PMT readout circuit [RD02]. APOCAT has the following main key features: 1. High-rate analog pulse height processing and energy resolved counting, simultaneously and asynchronously, in each channel (1Mcps/channel); 2. Low equivalent noise charge (ENC) for triggering and counting of single photons (<50fC ENC), 3. On-chip ADC (12-bit/2Msps), 4. High radiation tolerance. Samples have been manufactured and the design has been characterized. Work remains for flight model qualification.

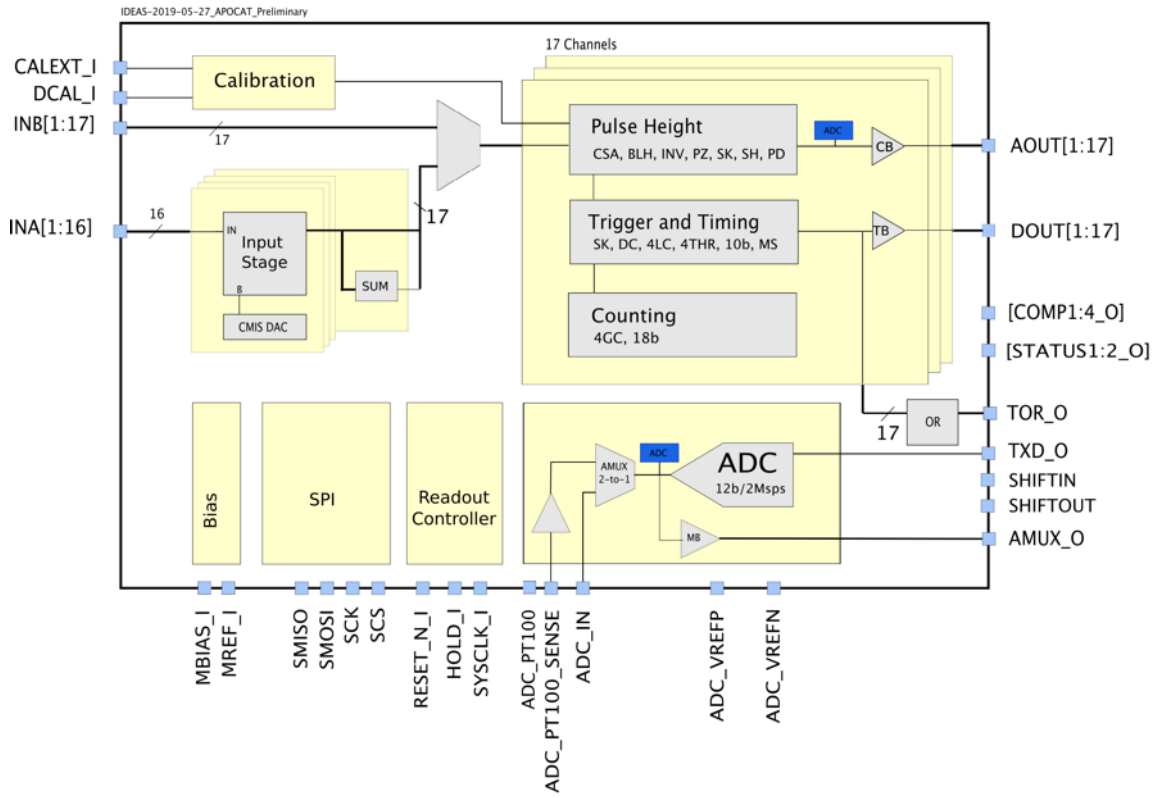

Figure 1: Block diagram of the IDE3381 APOCAT

Table 1 summarizes the key features of the circuit. The IC has 16 channels and 1 summing channel. Each channel can be used for high-resolution pulse-height spectroscopy, timing and 4-bin energy resolved 18-bit counting. The

readout was designed for high rates of about 1Mcps per channel. The channels can operate synchronously or asynchronously. The channel is programmable for peaking time of 50 ns, 150 ns, 300 ns, or 2000 ns to allow for pulse-height spectroscopy using various scintillators. Each channel has a current-mode input stage (CMIS) followed by a charge sensitive amplifier (CSA). The CMIS is designed for large negative charge and its attenuation can be programmed to be 1, 2.5, 5, 10, or 20. The CMIS input potential is programmable individually for each channel for operation with DC-coupled SiPM/MPPC array readout. The CMIS is ideal for relatively large detector capacitance (several nF) and large detector leakage currents (-10 µA from dark counts). The CMIS can be bypassed to allow for either positive or negative charge directly into the CSA. The CSAs have individually programmable conversion gain of 46, 48, 51, 53, 55 or 265mV/pC. The IC contains one 12-bit analog-to-digital converter (ADC) that allows for digitization of the pulse heights from all channels, including the summing channel at a sampling rate of 2Msps. Every channel has 2 outputs: one analog output for the pulse height and one digital output for the trigger/timing pulse with fixed width or time-over-threshold. The outputs facilitate many applications, such as external digitization, pulse height and time spectroscopy, pulse counting, triggering, and time-over-threshold. The IC operates at 3.3-V supply voltage and dissipates about 360mW with both CMIS and on-chip ADC active. To save power, any channel or function can be powered down. The ASIC has a serial peripheral interface (SPI) for programming its register settings and for the readout of ADC and counter data. Fast readout with up to 16 Mbit/s is possible via a serial data transmission line. The IC has been designed in a 0.35-µm CMOS process, and has a die size of 16420um x 14030um.

Table 1: APOCAT key features

16 inputs for readout of PMTs or SiPMs	Each with programmable input bias voltage 1Mcps/channel asynchronous or synchronous 16 analog outputs for amplitude spectroscopy 1 summing channel
30 programmable gain settings	5 max. charge at INA [pC]: -40, -100, -200, -400, -800 6 fine gain tunings [mV/pC]: 46, 48, 51, 53, 55, 265 Negative and positive charge at INB up to ±40pC
Globally programmable peaking time	50ns, 150ns, 300ns, 2000ns ENC 7fC@50ns, 15fC@150ns, 31fC@300ns
Pulse height spectroscopy	16+1 channels, shaped pulse and peak detector Digital readout with on-chip ADC (12b/2Msps) Possibility for external ADC per channel
Sample&Hold timing generation	Programmable sampling time, hold duration, and reset time External sampling control (optional)
Counting with on-chip counters	4 x 18bit counters per channel
SPI interface	
Radiation environment	TID: up to 340 krad(Si) without relevant change SEL: up to 137 MeV cm² / mg without latch-up SEU/SET LET threshold 18 MeV cm² / mg or larger
Power	360 mW with CMIS and on-chip ADC 20mW per channel with analog output buffer on Flexible and programmable power-down options Single supply voltage of 3.3V

REFERENCES

[RD01] Advanced Space-based Solar Observatory, Chinese Academy of Sciences

[RD02] D. Meier et al., "SIPHRA 16-Channel Silicon Photomultiplier Readout ASIC", Proc. AMICSA&DSP 2016, 12-16 June 2016, Gothenburg, Sweden. Available from https://doi.org/10.13140/RG.2.1.1460.8882